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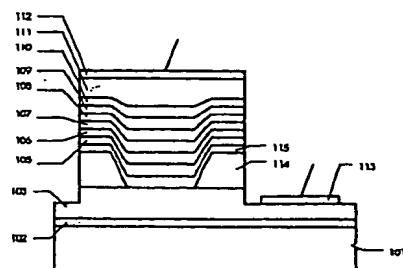
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(54) Gallium nitride based compound semiconductor laser and method of forming the same

(57) A method of forming a current block layer structure comprising the steps of providing dielectric stripe masks defining at least a stripe-shaped opening on a surface of a compound semiconductor region having a hexagonal crystal structure, and selectively growing at least a current block layer of a compound semiconductor having the hexagonal crystal structure on the surface of the compound semiconductor region by use of the dielectric stripe masks.

FIG. 3



101 : (0001)-face sapphire substrate
102 : 300 Å-thick undoped GaN buffer layer
103 : 3 μm-thick n-type GaN contact layer doped with Si
104 : 0.5 μm-thick p-type GaN current block layer doped with Mg
105 : 0.1 μm-thick n-type GaN cladding layer doped with Si
106 : 0.4 μm-thick n-type Al0.07Ga0.93N cladding layer doped with Si
107 : multiple quantum well active layer of 7 periods of
25 Å-thick undoped In0.3Ga0.7N quantum well layers and
50 Å-thick undoped In0.05Ga0.95N barrier layers
108 : 200 Å-thick p-type Al0.3Ga0.7N layer doped with Mg
109 : 0.1 μm-thick p-type GaN optical guide layer doped with Mg
110 : 0.4 μm-thick p-type Al0.07Ga0.93N cladding layer doped with Mg
111 : 0.2 μm-thick p-type GaN contact layer doped with Mg
112 : p-electrode
113 : n-electrode

Description

The present invention relates to a semiconductor laser diode and a method of forming the same, and more particularly to a gallium nitride based compound semiconductor laser having a current block layer structure selectively grown for a current confinement and a method of forming the same.

Gallium nitride is larger in energy band gap than those of indium phosphate and gallium arsenide, for which reason gallium nitride based semiconductors of $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) may be applied to light emitting diodes such as semiconductor laser diodes for emitting a light of an wavelength in the range of green light wavelength to ultraviolet ray wavelength.

Gallium nitride based semiconductor may have either hexagonal crystal structure or cubic crystal structure. The hexagonal crystal structure is more stable in energy than the cubic crystal structure.

One of conventional gallium nitride based semiconductor laser diodes is disclosed by S. Nakamura et al. in Extended Abstracts of 1996 International Conference On Solid State Devices And Materials, Yokohama, 1996, pp. 67-69.

The conventional gallium nitride based semiconductor laser diode will be described with reference to FIG. 1. A 300Å-thick undoped GaN buffer layer 102 is formed on a (11-20)-face sapphire substrate 201. A 3 μ m-thick n-type GaN contact layer 103 doped with Si is formed on the 300Å-thick undoped GaN buffer layer 102. A 0.1 μ m-thick n-type $In_{0.05}Ga_{0.95}N$ layer 104 doped with Si is formed on the 3 μ m-thick n-type GaN contact layer 103. A 0.4 μ m-thick n-type $Al_{0.07}Ga_{0.93}N$ cladding layer 105 doped with Si is formed on the 0.1 μ m-thick n-type $In_{0.05}Ga_{0.95}N$ layer 104. A 0.1 μ m-thick n-type GaN optical guide layer 106 doped with Si is formed on the 0.4 μ m-thick n-type $Al_{0.07}Ga_{0.93}N$ cladding layer 105. A multiple quantum well active layer 107 is formed on the 0.1 μ m-thick n-type GaN optical guide layer 106. The multiple quantum well active layer 107 comprises 7 periods of 30Å-thick undoped $In_{0.2}Ga_{0.8}N$ quantum well layers and 60Å-thick undoped $In_{0.05}Ga_{0.95}N$ barrier layers. A 200Å-thick p-type $Al_{0.2}Ga_{0.8}N$ layer 108 doped with Mg is formed on the multiple quantum well active layer 107. A 0.1 μ m-thick p-type GaN optical guide layer 109 doped with Mg is formed on the 200Å-thick p-type $Al_{0.2}Ga_{0.8}N$ layer 108. A 0.4 μ m-thick p-type $Al_{0.07}Ga_{0.93}N$ cladding layer 110 doped with Mg is formed on the 0.1 μ m-thick p-type GaN optical guide layer 109. A 0.2 μ m-thick p-type GaN contact layer 111 doped with Mg is formed on the 0.4 μ m-thick p-type $Al_{0.07}Ga_{0.93}N$ cladding layer 110. A p-electrode 112 is formed on the 0.2 μ m-thick p-type GaN contact layer 111. The p-electrode 112 comprises a nickel layer laminated on the top flat surface of the 0.2 μ m-thick p-type GaN contact layer 111 and a gold layer laminated on the nickel layer. An n-electrode 113 is provided

on the recessed surface of the 3 μ m-thick n-type GaN contact layer 103. The n-electrode 113 comprises a titanium layer laminated on the 3 μ m-thick n-type GaN contact layer 103 and an aluminum layer laminated on the titanium layer.

All of the semiconductor layers have hexagonal crystal structure with the (0001)-face grown over the (11-20)-face sapphire substrate 201.

The above conventional gallium nitride based semiconductor laser diode has no current confinement structure, for which reason the above conventional gallium nitride based semiconductor laser diode has a relatively large threshold current.

Other conventional gallium nitride based semiconductor laser diode is disclosed by S. Nakamura et al. in Applied Physics Letters, vol. 69 (1996), p. 1477. The other conventional gallium nitride based semiconductor laser diode will be described with reference to FIG. 2. A 300Å-thick undoped GaN buffer layer 102 is formed on a (11-20)-face sapphire substrate 201. A 3 μ m-thick n-type GaN contact layer 103 doped with Si is formed on the 300Å-thick undoped GaN buffer layer 102. A 0.1 μ m-thick n-type $In_{0.05}Ga_{0.95}N$ layer 104 doped with Si is formed on the 3 μ m-thick n-type GaN contact layer 103. A 0.5 μ m-thick n-type $Al_{0.05}Ga_{0.95}N$ cladding layer 605 doped with Si is formed on the 0.1 μ m-thick n-type $In_{0.05}Ga_{0.95}N$ layer 104. A 0.1 μ m-thick n-type GaN optical guide layer 106 doped with Si is formed on the 0.5 μ m-thick n-type $Al_{0.05}Ga_{0.95}N$ cladding layer 605. A multiple quantum well active layer 707 is formed on the 0.1 μ m-thick n-type GaN optical guide layer 106. The multiple quantum well active layer 707 comprises 7 periods of 30Å-thick undoped $In_{0.2}Ga_{0.8}N$ quantum well layers and 60Å-thick undoped $In_{0.05}Ga_{0.95}N$ barrier layers. A 200Å-thick p-type $Al_{0.2}Ga_{0.8}N$ layer 108 doped with Mg is formed on the multiple quantum well active layer 707. A 0.1 μ m-thick p-type GaN optical guide layer 109 doped with Mg is formed on the 200Å-thick p-type $Al_{0.2}Ga_{0.8}N$ layer 108. A 0.5 μ m-thick p-type $Al_{0.05}Ga_{0.95}N$ cladding layer 710 doped with Mg is formed on the 0.1 μ m-thick p-type GaN optical guide layer 109. A 0.2 μ m-thick p-type GaN contact layer 111 doped with Mg is formed on the 0.4 μ m-thick p-type $Al_{0.05}Ga_{0.95}N$ cladding layer 710. The 0.2 μ m-thick p-type GaN contact layer 111 has a ridge-shape. A p-electrode 112 is formed on the top portion of the 0.2 μ m-thick p-type GaN contact layer 111. The p-electrode 112 comprises a nickel layer laminated on the top flat surface of the 0.2 μ m-thick p-type GaN contact layer 111 and a gold layer laminated on the nickel layer. A silicon oxide film is formed which extends on the sloped side walls of the ridge portion of the 0.2 μ m-thick p-type GaN contact layer 111 and also on the flat base portions of the 0.2 μ m-thick p-type GaN contact layer 111 as well as on side walls of the above laminations of the 3 μ m-thick n-type GaN contact layer 103, the 0.1 μ m-thick n-type $In_{0.05}Ga_{0.95}N$ layer 104, the 0.5 μ m-thick n-type $Al_{0.05}Ga_{0.95}N$ cladding layer 605, the 0.1 μ m-thick n-

type GaN optical guide layer 106, the multiple quantum well active layer 707, the 200Å-thick p-type $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$ layer 108, the $0.1 \mu\text{m}$ -thick p-type GaN optical guide layer 109, the $0.4 \mu\text{m}$ -thick p-type $\text{Al}_{0.05}\text{Ga}_{0.95}\text{N}$ cladding layer 710 and the $0.2 \mu\text{m}$ -thick p-type GaN contact layer 111. An n-electrode 113 is provided on the recessed surface of the $3 \mu\text{m}$ -thick n-type GaN contact layer 103. The n-electrode 113 comprises a titanium layer laminated on the $3 \mu\text{m}$ -thick n-type GaN contact layer 103 and an aluminum layer laminated on the titanium layer.

All of the semiconductor layers have hexagonal crystal structure with the (0001)-face grown over the (11-20)-face sapphire substrate 201.

The above ridge structure of the $0.2 \mu\text{m}$ -thick p-type GaN contact layer 111 might contribute any current confinement for reduction in threshold current. Since, however, a contact area between the p-electrode and the $0.2 \mu\text{m}$ -thick p-type GaN contact layer 111 is small, a contact resistance of the p-electrode to the $0.2 \mu\text{m}$ -thick p-type GaN contact layer 111 is relatively large.

Whereas the above ridge structure of the $0.2 \mu\text{m}$ -thick p-type GaN contact layer 111 is defined by a dry etching process, this dry etching process may provide a damage to the semiconductor layers.

The use of this dry etching process results in complicated fabrication processes for the laser diode.

In the above circumstances, it had been required to develop a novel gallium nitride based compound semiconductor laser and a method of forming the same.

Accordingly, it is an object of the present invention to provide a novel gallium nitride based compound semiconductor laser free from the above problems.

It is a further object of the present invention to provide a novel gallium nitride based compound semiconductor laser having a current block layer structure for a current confinement.

It is a still further object of the present invention to provide a novel gallium nitride based compound semiconductor laser having a reduced threshold current.

It is yet a further object of the present invention to provide a novel gallium nitride based compound semiconductor laser having a reduced resistance to current.

It is a further more object of the present invention to provide a novel method of forming a novel gallium nitride based compound semiconductor laser having a current block layer structure for a current confinement.

It is still more object of the present invention to provide a novel method of forming a novel gallium nitride based compound semiconductor laser having a reduced threshold current.

It is yet more object of the present invention to provide a novel method of forming a novel gallium nitride based compound semiconductor laser having a reduced resistance to current.

It is moreover object of the present invention to provide a novel method of forming a current block layer structure in a novel gallium nitride based compound

semiconductor laser without use of dry etching process.

It is still more object of the present invention to provide a novel method of forming a current block layer structure in a novel gallium nitride based compound semiconductor laser at highly accurate size or dimensions.

The above and other objects, feature and advantage of the present invention will be apparent from the following descriptions.

10 The primary present invention provides a current block layer structure in a semiconductor device. The structure comprises at least a current block layer of a first compound semiconductor having a hexagonal crystal structure. The current block layer are selectively grown on at least a surface of a compound semiconductor region of a second compound semiconductor having the hexagonal crystal structure by use of dielectric stripe masks defining at least a stripe-shaped opening.

15 The other present invention provides a method of forming a current block layer structure comprising the steps of providing dielectric stripe masks defining at least a stripe-shaped opening on a surface of a compound semiconductor region having a hexagonal crystal structure, and selectively growing at least a current block layer of a compound semiconductor having the hexagonal crystal structure on the surface of the compound semiconductor region by use of the dielectric stripe masks.

20 Since the current block layer of a compound semiconductor having a hexagonal crystal structure is selectively grown on a compound semiconductor base region also having the hexagonal crystal structure by use of the dielectric stripe masks defining at least a stripe-shaped opening, for example, a metal organic chemical vapor

25 deposition method, then side walls of the current block layer have a good flatness. The selective growth using the dielectric stripe masks results in the highly flat side walls of the current block layer as compared to when a dry etching process is used. The selective growth using the dielectric stripe masks is superior in size-controllability as compared to when a dry etching process is used. The above selective growth using the dielectric stripe masks is more simple than the dry etching process. It is essential for the present invention that the compound semiconductor of the current block layer has the hexagonal crystal structure and the compound semiconductor base region also has the hexagonal crystal structure and also essential that the current block layer is formed by a selective growth using the dielectric stripe

30 masks defining the stripe-shaped opening. Namely, it is important for the present invention that the current block layer of the hexagonal crystal structure compound semiconductor is formed on the hexagonal crystal structure compound semiconductor base region by a selective growth using the dielectric stripe masks defining a stripe-shaped opening such as a metal organic chemical vapor deposition method. The current block layer selectively grown is capable of causing a current confine-

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ment or a current concentration which increases a current density whereby a threshold current is reduced if the above current clock structure is applied to a semiconductor laser.

Preferred embodiments of the present invention will be described in detail with reference to the accompanying drawings.

FIG. 1 is a fragmentary cross sectional elevation view illustrative of a conventional gallium nitride based compound semiconductor laser.

FIG. 2 is a fragmentary cross sectional elevation view illustrative of other conventional gallium nitride based compound semiconductor laser.

FIG. 3 is a fragmentary cross sectional elevation view illustrative of a novel gallium nitride based compound semiconductor laser having a current block layer structure for a current confinement in a first embodiment according to the present invention.

FIG. 4 is a fragmentary cross sectional elevation view illustrative of a novel gallium nitride based compound semiconductor laser in a selective growth process by a metal organic chemical vapor deposition method involved in a fabrication method thereof.

FIG. 5 is a fragmentary cross sectional elevation view illustrative of a novel gallium nitride based compound semiconductor laser having a current block layer structure for a current confinement in a second embodiment according to the present invention.

FIG. 6 is a fragmentary cross sectional elevation view illustrative of a novel gallium nitride based compound semiconductor laser in a selective growth process by a metal organic chemical vapor deposition method involved in a fabrication method thereof.

FIG. 7 is a fragmentary cross sectional elevation view illustrative of a novel gallium nitride based compound semiconductor laser having a current block layer structure for a current confinement in a third embodiment according to the present invention.

FIG. 8 is a fragmentary cross sectional elevation view illustrative of a novel gallium nitride based compound semiconductor laser in a selective growth process by a metal organic chemical vapor deposition method involved in a fabrication method thereof.

FIG. 9 is a fragmentary cross sectional elevation view illustrative of a novel gallium nitride based compound semiconductor laser having a current block layer structure for a current confinement in a fourth embodiment according to the present invention.

FIG. 10 is a fragmentary cross sectional elevation view illustrative of a novel gallium nitride based compound semiconductor laser in a selective growth process by a metal organic chemical vapor deposition method involved in a fabrication method thereof.

FIG. 11 is a fragmentary cross sectional elevation view illustrative of a novel gallium nitride based compound semiconductor laser having a current block layer structure for a current confinement in a fifth embodiment according to the present invention.

FIG. 12 is a fragmentary cross sectional elevation view illustrative of a novel gallium nitride based compound semiconductor laser in a selective growth process by a metal organic chemical vapor deposition method involved in a fabrication method thereof.

FIG. 13 is a fragmentary cross sectional elevation view illustrative of a novel gallium nitride based compound semiconductor laser having a current block layer structure for a current confinement in a sixth embodiment according to the present invention.

FIG. 14 is a fragmentary cross sectional elevation view illustrative of a novel gallium nitride based compound semiconductor laser in a selective growth process by a metal organic chemical vapor deposition method involved in a fabrication method thereof.

The first present invention provides a current block layer structure in a semiconductor device. The structure comprises at least a current block layer of a first compound semiconductor having a hexagonal crystal structure. The current block layer are selectively grown on at least a surface of a compound semiconductor region of a second compound semiconductor having the hexagonal crystal structure by use of dielectric stripe masks defining at least a stripe-shaped opening.

Since the current block layer of a compound semiconductor having a hexagonal crystal structure is selectively grown on a compound semiconductor base region also having the hexagonal crystal structure by use of the dielectric stripe masks defining at least a stripe-shaped opening, for example, a metal organic chemical vapor deposition method, then side walls of the current block layer have a good flatness. The selective growth using the dielectric stripe masks results in the highly flat side walls of the current block layer as compared to when a dry etching process is used.

The selective growth using the dielectric stripe masks is superior in size-controllability as compared to when a dry etching process is used. The above selective growth using the dielectric stripe masks is more simple than the dry etching process. It is essential for the present invention that the compound semiconductor of the current block layer has the hexagonal crystal structure and the compound semiconductor base region also has the hexagonal crystal structure and also essential that the current block layer is formed by a selective growth using the dielectric stripe masks defining the stripe-shaped opening. Namely, it is important for the present invention that the current block layer of the hexagonal crystal structure compound semiconductor is formed on the hexagonal crystal structure compound semiconductor base region by a selective growth using the dielectric stripe masks defining a stripe-shaped opening such as a metal organic chemical vapor deposition method.

The current block layer selectively grown is capable of causing a current confinement or a current concentration which increases a current density whereby a threshold current is reduced if the above current clock structure is applied to a semiconductor laser.

The above hexagonal crystal structure may have a (0001)-face or a face tilted from the (0001)-face by an angle in the range of 0 degree to 10 degrees. In this case, the dielectric stripe masks are set so that the stripe-shaped opening of the dielectric stripe masks have a longitudinal direction parallel to the [11-20] direction or direction having an included angle to a [11-20] direction in the range of -5 degrees to +5 degrees.

Alternatively, the above hexagonal crystal structure may have a (0001)-face or a face tilted from a (0001)-face by an angle in the range of 0 degree to 10 degrees. In this case, the dielectric stripe masks are set so that the stripe-shaped opening of the dielectric stripe masks have a longitudinal direction parallel to the [1-100] direction or direction having an included angle to a [1-100] direction in the range of -5 degrees to +5 degrees.

The compound semiconductor of the current block layer may be of an opposite conductivity type to that of the second compound semiconductor. In this case, the compound semiconductors of the current block layer and the compound semiconductor base region may be gallium nitride based semiconductors, for example, GaN, AlGaN, InGaN and InAlGaN, boron nitride based semiconductors.

Alternatively, the compound semiconductor of the current block layer has a highly resistive compound semiconductor such as an undoped semiconductor. In this case, the compound semiconductors of the current block layer and the compound semiconductor base region may also be gallium nitride based semiconductors, for example, GaN, AlGaN, InGaN and InAlGaN, boron nitride based semiconductors.

The compound semiconductor region may comprise a compound semiconductor base layer having a flat top surface. In this case, the current block layer is selectively grown on the flat top surface of the compound semiconductor base layer by use of the dielectric stripe masks provided on the flat top surface of the compound semiconductor base layer.

An additional compound semiconductor layer of the same conductivity type as the compound semiconductor base layer may be formed which extends on both side walls and a top surface of the current block layer and also extends over the compound semiconductor base layer under the stripe-shaped opening.

Alternatively, laminations of a plurality of additional compound semiconductor layers of the same conductivity type as the compound semiconductor base layer may be formed which extend on both side walls and a top surface of the current block layer and also extend over the compound semiconductor base layer under the stripe-shaped opening.

A side wall of the current block layer may be a vertical side wall or a sloped side wall.

The compound semiconductor base region may include at least a flat base portion and at least a ridged portion, and wherein the current block layer is selectively grown both on the flat base portion and on side walls

of the ridged portion by use of the dielectric stripe masks provided on a top portion of the ridged portion. The current block layer may comprise a single layer having a top surface which is substantially the same level as the top portion of the ridged portion or may comprise laminations of a plurality of different layers and the laminations have a top surface which is substantially the same level as the top portion of the ridged portion. In the latter case, the laminations may comprise a first layer having

an opposite conductivity type to the compound semiconductor region, a second layer being laminated on the first layer and having the same conductivity type as the compound semiconductor region, and a third layer being laminated on the second layer and having the opposite conductivity type to the compound semiconductor region. The ridged portion may include laminations of a plurality of different compound semiconductor layers. The ridged portion and the flat base portion comprise a single compound semiconductor layer having a ridged portion and etched portions.

The second present invention provides a gallium nitride based compound semiconductor laser having a current block layer structure. The current block layer structure comprises current block layers and at least an

additional compound semiconductor layer. The current block layers of a first compound semiconductor having a hexagonal crystal structure are selectively grown on a flat top surface of a compound semiconductor base layer of a second compound semiconductor having the hexagonal crystal structure by use of dielectric stripe masks defining at least a stripe-shaped opening and being provided on the flat top surface of the compound semiconductor base layer. The additional compound semiconductor layer of the same conductivity type as the compound semiconductor base layer extends on both side walls and top surfaces of the current block layers and also extends over the compound semiconductor base layer under the stripe-shaped opening.

Since the current block layer of a compound semiconductor having a hexagonal crystal structure is selectively grown on a compound semiconductor base region also having the hexagonal crystal structure by use of the dielectric stripe masks defining at least a stripe-shaped opening, for example, a metal organic chemical vapor deposition method, then side walls of the current block layer have a good flatness. The selective growth using the dielectric stripe masks results in the highly flat side walls of the current block layer as compared to when a dry etching process is used. The selective growth using the dielectric stripe masks is superior in size-controllability as compared to when a dry etching process is used. The above selective growth using the dielectric stripe masks is more simple than the dry etching process. It is essential for the present invention that the compound semiconductor of the current block layer has the hexagonal crystal structure and the compound semiconductor base region also has the hexagonal crystal structure and also essential that the current block layer

is formed by a selective growth using the dielectric stripe masks defining the stripe-shaped opening. Namely, it is important for the present invention that the current block layer of the hexagonal crystal structure compound semiconductor is formed on the hexagonal crystal structure compound semiconductor base region by a selective growth using the dielectric stripe masks defining a stripe-shaped opening such as a metal organic chemical vapor deposition method. The current block layer selectively grown is capable of causing a current confinement or a current concentration which increases a current density whereby a threshold current is reduced if the above current clock structure is applied to a semiconductor laser.

The above hexagonal crystal structure may have a (0001)-face or a face tilted from the (0001)-face by an angle in the range of 0 degree to 10 degrees. In this case, the dielectric stripe masks are set so that the stripe-shaped opening of the dielectric stripe masks have a longitudinal direction parallel to the [11-20] direction or direction having an included angle to a [11-20] direction in the range of -5 degrees to +5 degrees.

Alternatively, the above hexagonal crystal structure may have a (0001)-face or a face tilted from a (0001)-face by an angle in the range of 0 degree to 10 degrees. In this case, the dielectric stripe masks are set so that the stripe-shaped opening of the dielectric stripe masks have a longitudinal direction parallel to the [1-100] direction or direction having an included angle to a [1-100] direction in the range of -5 degrees to +5 degrees.

The compound semiconductor of the current block layer may be of an opposite conductivity type to that of the second compound semiconductor. In this case, the compound semiconductors of the current block layer and the compound semiconductor base region may be gallium nitride based semiconductors, for example, GaN, AlGaN, InGaN and InAlGaN, boron nitride based semiconductors,

Alternatively, the compound semiconductor of the current block layer has a highly resistive compound semiconductor such as an undoped semiconductor. In this case, the compound semiconductors of the current block layer and the compound semiconductor base region may also be gallium nitride based semiconductors, for example, GaN, AlGaN, InGaN and InAlGaN, boron nitride based semiconductors.

The compound semiconductor region may comprise a compound semiconductor base layer having a flat top surface. In this case, the current block layer is selectively grown on the flat top surface of the compound semiconductor base layer by use of the dielectric stripe masks provided on the flat top surface of the compound semiconductor base layer.

A side wall of the current block layer may be a vertical side wall or a sloped side wall.

The third present invention provides gallium nitride based compound semiconductor laser having a current block layer structure which comprises current block lay-

ers of a first compound semiconductor having a hexagonal crystal structure, the current block layers being selectively grown on both a flat base portion and side walls of a ridged portion of a compound semiconductor region of a second compound semiconductor having the hexagonal crystal structure by use of dielectric stripe masks defining at least a stripe-shaped opening and being provided on a top portion of the ridged portion.

Since the current block layer of a compound semiconductor having a hexagonal crystal structure is selectively grown on a compound semiconductor base region also having the hexagonal crystal structure by use of the dielectric stripe masks defining at least a stripe-shaped opening, for example, a metal organic chemical vapor deposition method, then side walls of the current block layer have a good flatness. The selective growth using the dielectric stripe masks results in the highly flat side walls of the current block layer as compared to when a dry etching process is used. The selective growth using the dielectric stripe masks is superior in size-controllability as compared to when a dry etching process is used. The above selective growth using the dielectric stripe masks is more simple than the dry etching process. It is essential for the present invention that the compound semiconductor of the current block layer has the hexagonal crystal structure and the compound semiconductor base region also has the hexagonal crystal structure and also essential that the current block layer is formed by a selective growth using the dielectric stripe masks defining the stripe-shaped opening. Namely, it is important for the present invention that the current block layer of the hexagonal crystal structure compound semiconductor is formed on the hexagonal crystal structure compound semiconductor base region by a selective growth using the dielectric stripe masks defining a stripe-shaped opening such as a metal organic chemical vapor deposition method. The current block layer selectively grown is capable of causing a current confinement or a current concentration which increases a current density whereby a threshold current is reduced if the above current clock structure is applied to a semiconductor laser.

The above hexagonal crystal structure may have a (0001)-face or a face tilted from the (0001)-face by an angle in the range of 0 degree to 10 degrees. In this case, the dielectric stripe masks are set so that the stripe-shaped opening of the dielectric stripe masks have a longitudinal direction parallel to the [11-20] direction or direction having an included angle to a [11-20] direction in the range of -5 degrees to +5 degrees.

Alternatively, the above hexagonal crystal structure may have a (0001)-face or a face tilted from a (0001)-face by an angle in the range of 0 degree to 10 degrees. In this case, the dielectric stripe masks are set so that the stripe-shaped opening of the dielectric stripe masks have a longitudinal direction parallel to the [1-100] direction or direction having an included angle to a [1-100] direction in the range of -5 degrees to +5 degrees.

The compound semiconductor of the current block layer may be of an opposite conductivity type to that of the second compound semiconductor. In this case, the compound semiconductors of the current block layer and the compound semiconductor base region may be gallium nitride based semiconductors, for example, GaN, AlGaN, InGaN and InAlGaN, boron nitride based semiconductors.

Alternatively, the compound semiconductor of the current block layer has a highly resistive compound semiconductor such as an undoped semiconductor. In this case, the compound semiconductors of the current block layer and the compound semiconductor base region may also be gallium nitride based semiconductors, for example, GaN, AlGaN, InGaN and InAlGaN, boron nitride based semiconductors.

Each of the current block layers may comprise a single layer having a top surface which is substantially the same level as the top portion of the ridged portion.

Alternatively, each of the current block layers may comprise laminations of a plurality of different layers and the laminations have a top surface which is substantially the same level as the top portion of the ridged portion. In this case, the laminations may comprise a first layer having an opposite conductivity type to the compound semiconductor region, a second layer being laminated on the first layer and having the same conductivity type as the compound semiconductor region, and a third layer being laminated on the second layer and having the opposite conductivity type to the compound semiconductor region.

The ridged portion may include laminations of a plurality of different compound semiconductor layers.

The ridged portion and the flat base portion may comprise a single compound semiconductor layer having a ridged portion and etched portions.

The fourth present invention provides a gallium nitride based compound semiconductor laser comprising a substrate, a first $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer of a first conductivity type formed over the substrate and the first $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer having a hexagonal crystal structure, $In_xGa_{1-x}N$ ($0 \leq x \leq 1$) current block layers having the hexagonal crystal structure being selectively grown on a flat surface of the first $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer by use of dielectric stripe masks defining a ridge-shaped opening and being provided on the flat surface of the first $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer, a second $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer of the first conductivity type being formed which extends on both side walls and top surfaces of the current block layers and also extends over the first $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer, an active region of an $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) compound semiconductor formed over the second $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer, and a third $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) lay-

er of a second conductivity type formed over the active region.

The fifth present invention provides a gallium nitride based compound semiconductor laser comprising a substrate, a first $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer of a first conductivity type formed over the substrate and the first $InAlGaN$ layer having a hexagonal crystal structure, an active region of an $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) compound semiconductor having the hexagonal crystal structure and being formed over the first $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer, a second $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer of a second conductivity type being formed on the active region and the second $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer having the hexagonal crystal structure, dielectric stripe masks being provided on the second $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer and the dielectric stripe masks defining a stripe-shaped opening, and an $In_xGa_{1-x}N$ ($0 \leq x \leq 1$) layer of the second conductivity type having the hexagonal crystal structure being selectively grown by use of the dielectric stripe masks so that the $In_xGa_{1-x}N$ ($0 \leq x \leq 1$) layer extends over the stripe-shaped opening and also extends over parts of the dielectric stripe masks whereby the $In_xGa_{1-x}N$ ($0 \leq x \leq 1$) layer has a ridge-shape.

The sixth present invention provides a gallium nitride based compound semiconductor laser comprising a substrate, a first $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer of a first conductivity type formed over the substrate and the first $InAlGaN$ layer having a hexagonal crystal structure, an active region of an $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) compound semiconductor having the hexagonal crystal structure and being formed over the first $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer, a second $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer of a second conductivity type being formed on the active region and the second $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer having the hexagonal crystal structure, $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) current block layers having the hexagonal crystal structure being selectively grown on a flat surface of the second $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer by use of dielectric stripe masks defining a ridge-shaped opening and being provided on the flat surface of the second $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer, and an $In_xGa_{1-x}N$ ($0 \leq x \leq 1$) layer of the second conductivity type having the hexagonal crystal structure being formed which extends on both side walls and top surfaces of the $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) current block layers and also extends over the second $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer.

The seventh present invention provides a gallium nitride based compound semiconductor laser comprising a substrate, a first $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer of a first conductivity type being formed on a part of the substrate and the first $In_xAl_yGa_{1-x-y}N$

($0 \leq x \leq 1, 0 \leq y \leq 1, 0 \leq x+y \leq 1$) layer having a hexagonal crystal structure and the first $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1, 0 \leq y \leq 1, 0 \leq x+y \leq 1$) layer having a ridged portion, an active region of an $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1, 0 \leq y \leq 1, 0 \leq x+y \leq 1$) compound semiconductor being formed on the ridged portion of the first $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1, 0 \leq y \leq 1, 0 \leq x+y \leq 1$) layer, a second $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1, 0 \leq y \leq 1, 0 \leq x+y \leq 1$) layer of a second conductivity type being formed on the active region thereby to form a ridge-structure on the substrate, wherein the ridge-structure comprising laminations of the first $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1, 0 \leq y \leq 1, 0 \leq x+y \leq 1$) layer, the active region and the second $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1, 0 \leq y \leq 1, 0 \leq x+y \leq 1$) layer, $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1, 0 \leq y \leq 1, 0 \leq x+y \leq 1$) current block layers having the hexagonal crystal structure being selectively grown on side walls of the ridged-structure and over the first $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1, 0 \leq y \leq 1, 0 \leq x+y \leq 1$) layer by use of dielectric stripe mask provided on the ridge-structure, and a third $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1, 0 \leq y \leq 1, 0 \leq x+y \leq 1$) layer of the second conductivity type being formed over the $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1, 0 \leq y \leq 1, 0 \leq x+y \leq 1$) current block layers and a top of the ridged-structure.

The eighth present invention provides a gallium nitride based compound semiconductor laser comprising a substrate, a first $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1, 0 \leq y \leq 1, 0 \leq x+y \leq 1$) layer of a first conductivity type being formed on the substrate and the first $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1, 0 \leq y \leq 1, 0 \leq x+y \leq 1$) layer having a hexagonal crystal structure and the first $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1, 0 \leq y \leq 1, 0 \leq x+y \leq 1$) layer having a ridged portion, an active region of an $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1, 0 \leq y \leq 1, 0 \leq x+y \leq 1$) compound semiconductor being formed on the first $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1, 0 \leq y \leq 1, 0 \leq x+y \leq 1$) layer, a second $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1, 0 \leq y \leq 1, 0 \leq x+y \leq 1$) layer of a second conductivity type being formed on the active region and the second $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1, 0 \leq y \leq 1, 0 \leq x+y \leq 1$) layer having a ridge portion and flat base portions, $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1, 0 \leq y \leq 1, 0 \leq x+y \leq 1$) current block layers having the hexagonal crystal structure being selectively grown on side walls of the ridge portion and over the flat base portions by use of dielectric stripe mask provided on the ridge portion, and a third $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1, 0 \leq y \leq 1, 0 \leq x+y \leq 1$) layer of the second conductivity type being formed over the $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1, 0 \leq y \leq 1, 0 \leq x+y \leq 1$) current block layers and a top of the ridge portion.

The ninth present invention provides a current confinement structure in a semiconductor laser, comprising dielectric stripe masks defining a stripe-shaped opening and being provided on a flat surface of a compound semiconductor base layer having a hexagonal crystal structure, and a compound semiconductor ridge-shaped layer of a hexagonal crystal structure being selectively grown in the stripe-shaped opening over the compound semiconductor base layer as well as over parts of the dielectric stripe masks. The current block

layer may selectively be grown by a metal organic chemical vapor deposition method.

Since the compound semiconductor ridge-shaped layer of a compound semiconductor having a hexagonal crystal structure is selectively grown on a compound semiconductor base region also having the hexagonal crystal structure by use of the dielectric stripe masks defining at least a stripe-shaped opening, for example, a metal organic chemical vapor deposition method, then side walls of the compound semiconductor ridge-shaped layer have a good flatness. The selective growth using the dielectric stripe masks results in the highly flat side walls of the current block layer as compared to when a dry etching process is used. The selective growth using the dielectric stripe masks is superior in size-controllability as compared to when a dry etching process is used. The above selective growth using the dielectric stripe masks is more simple than the dry etching process. It is essential for the present invention that the compound semiconductor of the compound semiconductor ridge-shaped layer has the hexagonal crystal structure and the compound semiconductor base region also has the hexagonal crystal structure and also essential that the compound semiconductor ridge-shaped layer is formed by a selective growth using the dielectric stripe masks defining the stripe-shaped opening. Namely, it is important for the present invention that the compound semiconductor ridge-shaped layer of the hexagonal crystal structure is formed on the hexagonal crystal structure compound semiconductor base region by a selective growth using the dielectric stripe masks defining a stripe-shaped opening such as a metal organic chemical vapor deposition method. The current block layer selectively grown is capable of causing a current confinement or a current concentration which increases a current density whereby a threshold current is reduced if the above compound semiconductor ridge-shaped layer is applied to a semiconductor laser.

The above hexagonal crystal structure may have a (0001)-face or a face tilted from the (0001)-face by an angle in the range of 0 degree to 10 degrees. In this case, the dielectric stripe masks are set so that the stripe-shaped opening of the dielectric stripe masks have a longitudinal direction parallel to the [11-20] direction or direction having an included angle to a [11-20] direction in the range of -5 degrees to +5 degrees.

Alternatively, the above hexagonal crystal structure may have a (0001)-face or a face tilted from a (0001)-face by an angle in the range of 0 degree to 10 degrees. In this case, the dielectric stripe masks are set so that the stripe-shaped opening of the dielectric stripe masks have a longitudinal direction parallel to the [1-100] direction or direction having an included angle to a [1-100] direction in the range of -5 degrees to +5 degrees.

The tenth present invention provides a method of forming a current block layer structure comprising the steps of providing dielectric stripe masks defining at least a stripe-shaped opening on a surface of a com-

compound semiconductor region having a hexagonal crystal structure, and selectively growing at least a current block layer of a compound semiconductor having the hexagonal crystal structure on the surface of the compound semiconductor region by use of the dielectric stripe masks.

Since the current block layer of a compound semiconductor having a hexagonal crystal structure is selectively grown on a compound semiconductor base region also having the hexagonal crystal structure by use of the dielectric stripe masks defining at least a stripe-shaped opening, for example, a metal organic chemical vapor deposition method, then side walls of the current block layer have a good flatness. The selective growth using the dielectric stripe masks results in the highly flat side walls of the current block layer as compared to when a dry etching process is used. The selective growth using the dielectric stripe masks is superior in size-controllability as compared to when a dry etching process is used. The above selective growth using the dielectric stripe masks is more simple than the dry etching process. It is essential for the present invention that the compound semiconductor of the current block layer has the hexagonal crystal structure and the compound semiconductor base region also has the hexagonal crystal structure and also essential that the current block layer is formed by a selective growth using the dielectric stripe masks defining the stripe-shaped opening. Namely, it is important for the present invention that the current block layer of the hexagonal crystal structure compound semiconductor is formed on the hexagonal crystal structure compound semiconductor base region by a selective growth using the dielectric stripe masks defining a stripe-shaped opening such as a metal organic chemical vapor deposition method. The current block layer selectively grown is capable of causing a current confinement or a current concentration which increases a current density whereby a threshold current is reduced if the above current block structure is applied to a semiconductor laser.

The above hexagonal crystal structure may have a (0001)-face or a face tilted from the (0001)-face by an angle in the range of 0 degree to 10 degrees. In this case, the dielectric stripe masks are set so that the stripe-shaped opening of the dielectric stripe masks have a longitudinal direction parallel to the [11-20] direction or direction having an included angle to a [11-20] direction in the range of -5 degrees to +5 degrees.

Alternatively, the above hexagonal crystal structure may have a (0001)-face or a face tilted from a (0001)-face by an angle in the range of 0 degree to 10 degrees. In this case, the dielectric stripe masks are set so that the stripe-shaped opening of the dielectric stripe masks have a longitudinal direction parallel to the [1-100] direction or direction having an included angle to a [1-100] direction in the range of -5 degrees to +5 degrees.

The compound semiconductor of the current block layer may be of an opposite conductivity type to that of

the compound semiconductor region. In this case, the method as claimed in claim 108, wherein the compound semiconductor of the current block layer and the compound semiconductor region may be gallium nitride based semiconductors or boron nitride based semiconductors.

Alternatively, the compound semiconductor of the current block layer may have a highly resistive compound semiconductor such as an undoped semiconductor.

The compound semiconductor region may comprise a compound semiconductor base layer having a flat top surface, and wherein the current block layer is selectively grown on the flat top surface of the compound semiconductor base layer by use of the dielectric stripe masks provided on the flat top surface of the compound semiconductor base layer.

An additional compound semiconductor layer of the same conductivity type as the compound semiconductor base layer may further be formed so that the additional compound semiconductor layer extends on both side walls and a top surface of the current block layer and also extends over the compound semiconductor base layer under the stripe-shaped opening under the stripe-shaped opening.

Alternatively, laminations of a plurality of additional compound semiconductor layers of the same conductivity type as the compound semiconductor base layer may further be formed so that the laminations of the plurality of additional compound semiconductor layers extend on both side walls and a top surface of the current block layer and also extend over the compound semiconductor base layer under the stripe-shaped opening.

The compound semiconductor region may include at least a flat base portion and at least a ridged portion, and wherein the current block layer is selectively grown both on the flat base portion and on side walls of the ridged portion by use of the dielectric stripe masks provided on a top portion of the ridged portion.

Alternatively, the current block layer may comprise a single layer having a top surface which is substantially the same level as the top portion of the ridged portion.

Further alternatively, the current block layer may comprise laminations of a plurality of different layers and the laminations have a top surface which is substantially the same level as the top portion of the ridged portion. In this case, the laminations are formed by depositing a first layer having an opposite conductivity type to the compound semiconductor region, depositing a second layer being laminated on the first layer and having the same conductivity type as the compound semiconductor region over the first layer, and a third layer being laminated on the second layer and having the opposite conductivity type to the compound semiconductor region over the second layer.

The eleventh present invention provides a method of forming a current block layer structure in a gallium nitride based compound semiconductor laser, compris-

ing the steps of providing dielectric stripe masks defining at least a stripe-shaped opening on a flat surface of a compound semiconductor region having a hexagonal crystal structure, selectively growing at least a ridge-shaped current block layer of a compound semiconductor having the hexagonal crystal structure on the surface of the compound semiconductor region by use of the dielectric stripe masks, and forming at least an additional compound semiconductor layer of the same conductivity type as the compound semiconductor base layer so that the additional compound semiconductor layer extends on both side walls and a top surface of the current block layer and also extends over the compound semiconductor base layer under the stripe-shaped opening under the stripe-shaped opening. The current block layer may selectively be grown by a metal organic chemical vapor deposition method.

Since the current block layer of a compound semiconductor having a hexagonal crystal structure is selectively grown on a compound semiconductor base region also having the hexagonal crystal structure by use of the dielectric stripe masks defining at least a stripe-shaped opening, for example, a metal organic chemical vapor deposition method, then side walls of the current block layer have a good flatness. The selective growth using the dielectric stripe masks results in the highly flat side walls of the current block layer as compared to when a dry etching process is used. The selective growth using the dielectric stripe masks is superior in size-controllability as compared to when a dry etching process is used. The above selective growth using the dielectric stripe masks is more simple than the dry etching process. It is essential for the present invention that the compound semiconductor of the current block layer has the hexagonal crystal structure and the compound semiconductor base region also has the hexagonal crystal structure and also essential that the current block layer is formed by a selective growth using the dielectric stripe masks defining the stripe-shaped opening. Namely, it is important for the present invention that the current block layer of the hexagonal crystal structure compound semiconductor is formed on the hexagonal crystal structure compound semiconductor base region by a selective growth using the dielectric stripe masks defining a stripe-shaped opening such as a metal organic chemical vapor deposition method. The current block layer selectively grown is capable of causing a current confinement or a current concentration which increases a current density whereby a threshold current is reduced if the above current block structure is applied to a semiconductor laser.

The above hexagonal crystal structure may have a (0001)-face or a face tilted from the (0001)-face by an angle in the range of 0 degrees to 10 degrees. In this case, the dielectric stripe masks are set so that the stripe-shaped opening of the dielectric stripe masks have a longitudinal direction parallel to the [11-20] direction or direction having an included angle to a [11-20]

direction in the range of -5 degrees to +5 degrees.

Alternatively, the above hexagonal crystal structure may have a (0001)-face or a face tilted from a (0001)-face by an angle in the range of 0 degree to 10 degrees.

- 5 In this case, the dielectric stripe masks are set so that the stripe-shaped opening of the dielectric stripe masks have a longitudinal direction parallel to the [1-100] direction or direction having an included angle to a [1-100] direction in the range of -5 degrees to +5 degrees.
- 10 The compound semiconductor of the current block layer may be of an opposite conductivity type to that of the compound semiconductor region.
- 15 The compound semiconductor of the current block layer and the compound semiconductor region may be gallium nitride based semiconductors or boron nitride based semiconductors.
- 20 The compound semiconductor of the current block layer may have a highly resistive compound semiconductor such as an undoped semiconductor.
- 25 The twelfth present invention provides a method of forming a current block layer structure in a gallium nitride based compound semiconductor laser, comprising the steps of forming flat base portions and ridged portions of a compound semiconductor region, providing dielectric stripe masks defining at least a stripe-shaped opening on the ridged portion of the compound semiconductor region having a hexagonal crystal structure, and selectively growing at least a current block layer of a compound semiconductor having the hexagonal crystal structure both on the flat base portion and on side walls of the ridged portion by use of the dielectric stripe masks. The current block layer is selectively grown by a metal organic chemical vapor deposition method.
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- 35 Since the current block layer of a compound semiconductor having a hexagonal crystal structure is selectively grown on a compound semiconductor base region also having the hexagonal crystal structure by use of the dielectric stripe masks defining at least a stripe-shaped opening, for example, a metal organic chemical vapor deposition method, then side walls of the current block layer have a good flatness. The selective growth using the dielectric stripe masks results in the highly flat side walls of the current block layer as compared to when a dry etching process is used. The selective growth using the dielectric stripe masks is superior in size-controllability as compared to when a dry etching process is used. The above selective growth using the dielectric stripe masks is more simple than the dry etching process. It is essential for the present invention that the compound semiconductor of the current block layer has the hexagonal crystal structure and the compound semiconductor base region also has the hexagonal crystal structure and also essential that the current block layer is formed by a selective growth using the dielectric stripe masks defining the stripe-shaped opening. Namely, it is important for the present invention that the current block layer of the hexagonal crystal structure compound semiconductor is formed on the hexagonal crystal structure
- 40
- 45
- 50
- 55

compound semiconductor base region by a selective growth using the dielectric stripe masks defining a stripe-shaped opening such as a metal organic chemical vapor deposition method. The current block layer selectively grown is capable of causing a current confinement or a current concentration which increases a current density whereby a threshold current is reduced if the above current clock structure is applied to a semiconductor laser.

The above hexagonal crystal structure may have a (0001)-face or a face tilted from the (0001)-face by an angle in the range of 0 degree to 10 degrees. In this case, the dielectric stripe masks are set so that the stripe-shaped opening of the dielectric stripe masks have a longitudinal direction parallel to the [11-20] direction or direction having an included angle to a [11-20] direction in the range of -5 degrees to +5 degrees.

Alternatively, the above hexagonal crystal structure may have a (0001)-face or a face tilted from a (0001)-face by an angle in the range of 0 degree to 10 degrees. In this case, the dielectric stripe masks are set so that the stripe-shaped opening of the dielectric stripe masks have a longitudinal direction parallel to the [1-100] direction or direction having an included angle to a [1-100] direction in the range of -5 degrees to +5 degrees.

The compound semiconductor of the current block layer may be of an opposite conductivity type to that of the compound semiconductor region.

The compound semiconductor of the current block layer and the compound semiconductor region may be gallium nitride based semiconductors or boron nitride based semiconductors.

The compound semiconductor of the current block layer may have a highly resistive compound semiconductor such as an undoped semiconductor.

The current block layer may comprise a single layer having a top surface which is substantially the same level as the top portion of the ridged portion.

The current block layer may also comprise laminations of a plurality of different layers and the laminations have a top surface which is substantially the same level as the top portion of the ridged portion. In this case, the laminations may be formed by depositing a first layer having an opposite conductivity type to the compound semiconductor region, depositing a second layer being laminated on the first layer and having the same conductivity type as the compound semiconductor region over the first layer, and a third layer being laminated on the second layer and having the opposite conductivity type to the compound semiconductor region over the second layer.

The thirteenth present invention provides a method of forming a current confinement structure in a gallium nitride based compound semiconductor laser, comprising the steps of providing dielectric stripe masks defining at least a stripe-shaped opening on a flat surface of a compound semiconductor region having a hexagonal crystal structure, and selectively growing a compound

semiconductor ridge-shaped layer of a hexagonal crystal structure in the stripe-shaped opening over the compound semiconductor base layer as well as over parts of the dielectric stripe masks. The compound semiconductor ridge-shaped layer may selectively be grown by a metal organic chemical vapor deposition method.

Since the current block layer of a compound semiconductor having a hexagonal crystal structure is selectively grown on a compound semiconductor base region

10 also having the hexagonal crystal structure by use of the dielectric stripe masks defining at least a stripe-shaped opening, for example, a metal organic chemical vapor deposition method, then side walls of the compound semiconductor ridge-shaped layer have a good flatness. The selective growth using the dielectric stripe masks results in the highly flat side walls of the compound semiconductor ridge-shaped layer as compared to when a dry etching process is used. The selective growth using the dielectric stripe masks is superior in size-controllability as compared to when a dry etching process is used. The above selective growth using the dielectric stripe masks is more simple than the dry etching process. It is essential for the present invention that the compound semiconductor of the compound semiconductor ridge-shaped layer has the hexagonal crystal structure and the compound semiconductor base region also has the hexagonal crystal structure and also essential that the compound semiconductor ridge-shaped layer is formed by a selective growth using the dielectric stripe masks defining the stripe-shaped opening. Namely, it is important for the present invention that the compound semiconductor ridge-shaped layer of the hexagonal crystal structure compound semiconductor is formed on the hexagonal crystal structure compound semiconductor base region by a selective growth using the dielectric stripe masks defining a stripe-shaped opening such as a metal organic chemical vapor deposition method. The compound semiconductor ridge-shaped layer selectively grown is capable of causing a current confinement or a current concentration which increases a current density whereby a threshold current is reduced if the above current clock structure is applied to a semiconductor laser.

The above hexagonal crystal structure may have a (0001)-face or a face tilted from the (0001)-face by an angle in the range of 0 degree to 10 degrees. In this case, the dielectric stripe masks are set so that the stripe-shaped opening of the dielectric stripe masks have a longitudinal direction parallel to the [11-20] direction or direction having an included angle to a [11-20] direction in the range of -5 degrees to +5 degrees.

Alternatively, the above hexagonal crystal structure may have a (0001)-face or a face tilted from a (0001)-face by an angle in the range of 0 degree to 10 degrees. In this case, the dielectric stripe masks are set so that the stripe-shaped opening of the dielectric stripe masks have a longitudinal direction parallel to the [1-100] direction or direction having an included angle to a [1-100]

direction in the range of -5 degrees to +5 degrees.

The compound semiconductor region and the compound semiconductor ridge-shaped layer may be made of one selected from the group consisting of gallium nitride based semiconductors and boron nitride based semiconductors.

FIRST EMBODIMENT:

A first embodiment according to the present invention will be described with reference to FIGS. 3 and 4. FIG. 3 is a fragmentary cross sectional elevation view illustrative of a novel gallium nitride based compound semiconductor laser having a current block layer structure for a current confinement in a first embodiment according to the present invention. FIG. 4 is a fragmentary cross sectional elevation view illustrative of a novel gallium nitride based compound semiconductor laser in a selective growth process by a metal organic chemical vapor deposition method involved in a fabrication method thereof.

The novel gallium nitride based compound semiconductor laser is formed on a (0001)-face sapphire substrate 101. All of compound semiconductor layers in the novel gallium nitride based compound semiconductor laser have hexagonal crystal structures. The structure of the novel gallium nitride based compound semiconductor laser is as follows. A 300Å-thick undoped GaN buffer layer 102 is provided on a (0001)-face sapphire substrate 101.

The 300Å-thick undoped GaN buffer layer 102 has a hexagonal crystal structure. A 3 μ m-thick n-type GaN contact layer 103 doped with Si is provided on an entire surface of the 300Å-thick undoped GaN buffer layer 102. The 3 μ m-thick n-type GaN contact layer 103 has a hexagonal crystal structure. The 3 μ m-thick n-type GaN contact layer 103 has a ridged portion and recess portions. A top surface of the ridged portion of the 3 μ m-thick n-type GaN contact layer 103 is a flat surface. Upper surfaces of the recess portions of the 3 μ m-thick n-type GaN contact layer 103 are also flat surfaces. Further, 0.5 μ m-thick p-type GaN current block layers 114 doped with Mg are selectively provided on the top flat surface of the ridged portion of the 3 μ m-thick n-type GaN contact layer 103. The 0.5 μ m-thick p-type GaN current block layers 114 also have the hexagonal crystal structure. As will be described later, the 0.5 μ m-thick p-type GaN current block layers 114 are formed by a selective growth of a metal organic chemical vapor deposition method using dielectric stripe masks, for which reason the 0.5 μ m-thick p-type GaN current block layers 114 have highly flat and sloped inside walls. It is important that the 0.5 μ m-thick p-type GaN current block layers 114 having the hexagonal crystal structure are selectively grown by the metal organic chemical vapor deposition method using dielectric stripe masks on the 3 μ m-thick n-type GaN contact layer 103 having the hexagonal crystal structure. This results in the formation

of the highly flat and sloped inside walls of the 0.5 μ m-thick p-type GaN current block layers 114. The highly flat and sloped inside walls of the 0.5 μ m-thick p-type GaN current block layers 114 cause current confinement as will be described later. A 0.1 μ m-thick n-type GaN cladding layer 115 doped with Si is then provided which extends on the top and flat surfaces and the above highly flat sloped inside walls of the 0.5 μ m-thick p-type GaN current block layers 114 as well as on an uncovered part of a top surface of the 3 μ m-thick n-type GaN contact layer 103. The 0.1 μ m-thick n-type GaN cladding layer 115 has the hexagonal crystal structure. A 0.4 μ m-thick n-type $Al_{0.07}Ga_{0.93}N$ cladding layer 105 doped with Si is provided on the 0.1 μ m-thick n-type GaN cladding layer 115. The 0.411 μ m-thick n-type $Al_{0.07}Ga_{0.93}N$ cladding layer 105 has the hexagonal crystal structure. A 0.1 μ m-thick n-type GaN optical guide layer 106 doped with Si is provided on the 0.4 μ m-thick n-type $Al_{0.07}Ga_{0.93}N$ cladding layer 105. The 0.1 μ m-thick n-type GaN optical guide layer 106 has the hexagonal crystal structure. A multiple quantum well active layer 107 is provided on the 0.1 μ m-thick n-type GaN optical guide layer 106. The multiple quantum well active layer 107 comprises 7 periods of alternating 25Å-thick undoped $In_{0.2}Ga_{0.8}N$ quantum well layers and 50Å-thick undoped $In_{0.05}Ga_{0.95}N$ barrier layers. The 25 Å-thick undoped $In_{0.2}Ga_{0.8}N$ quantum well layers have the hexagonal crystal structure. The 50Å-thick undoped $In_{0.05}Ga_{0.95}N$ barrier layers have the hexagonal crystal structure. A 200Å-thick p-type $Al_{0.2}Ga_{0.8}N$ layer 108 doped with Mg is provided on the multiple quantum well active layer 107. The 200Å-thick p-type $Al_{0.2}Ga_{0.8}N$ layer 108 has the hexagonal crystal structure. A 0.1 μ m-thick p-type GaN optical guide layer 109 doped with Mg is provided on the 200Å-thick p-type $Al_{0.2}Ga_{0.8}N$ layer 108. The 0.1 μ m-thick p-type GaN optical guide layer 109 has the hexagonal crystal structure. A 0.4 μ m-thick p-type $Al_{0.07}Ga_{0.93}N$ cladding layer 110 doped with Mg is provided on the 0.1 μ m-thick p-type GaN optical guide layer 109. The 0.4 μ m-thick p-type $Al_{0.07}Ga_{0.93}N$ cladding layer 110 has the hexagonal crystal structure. There are differences in level of the 0.1 μ m-thick n-type GaN cladding layer 115, the 0.4 μ m-thick n-type $Al_{0.07}Ga_{0.93}N$ cladding layer 105, the 0.1 μ m-thick n-type GaN optical guide layer 106, the multiple quantum well active layer 107, the 200Å-thick p-type $Al_{0.2}Ga_{0.8}N$ layer 108, the 0.1 μ m-thick p-type GaN optical guide layer 109 and the 0.4 μ m-thick p-type $Al_{0.07}Ga_{0.93}N$ cladding layer 110. A 0.2 μ m-thick p-type GaN contact layer 111 doped with Mg is provided on the 0.4 μ m-thick p-type $Al_{0.07}Ga_{0.93}N$ cladding layer 110. A top surface of the 0.2 μ m-thick p-type GaN contact layer 111 is flat. The 0.2 μ m-thick p-type GaN contact layer 111 has the hexagonal crystal structure. A p-electrode 112 is provided on the top flat surface of the 0.2 μ m-thick p-type GaN contact layer 111. The p-electrode 112 comprises a nickel layer laminated on the top flat surface of the 0.2 μ m-thick p-type GaN contact layer 111 and a gold layer lam-

inated on the nickel layer. An n-electrode 113 is provided on the recessed surface of the 3 μ m-thick n-type GaN contact layer 103. The n-electrode 113 comprises a titanium layer laminated on the 3 μ m-thick n-type GaN contact layer 103 and an aluminum layer laminated on the titanium layer.

As described above, since the 0.5 μ m-thick p-type GaN current block layers 114 have an opposite conductivity type to that of the 3 μ m-thick n-type GaN contact layer 103 and the 0.1 μ m-thick n-type GaN cladding layer 115 as well as the 0.4 μ m-thick n-type $Al_{0.07}Ga_{0.93}N$ cladding layer 105, then the 0.5 μ m-thick p-type GaN current block layers 114 are capable of blocking or guiding a current for current confinement. This current confinement allows a reduction in threshold current of the laser diode.

The above laser diode is formed as follows. The 300Å-thick undoped GaN buffer layer 102 is grown by a metal organic chemical vapor deposition method at a low temperature on the flat (0001)-face sapphire substrate 101 so that the 300Å-thick undoped GaN buffer layer 102 has a hexagonal crystal structure. The 3 μ m-thick n-type GaN contact layer 103 doped with Si is grown by a metal organic chemical vapor deposition method on an entire surface of the 300Å-thick undoped GaN buffer layer 102 so that the 3 μ m-thick n-type GaN contact layer 103 has a hexagonal crystal structure. Silicon oxide stripe masks 215 having a width of 1 micrometer are arranged in a [11-20] direction of the hexagonal crystal structure of the 3 μ m-thick n-type GaN contact layer 103. The silicon oxide stripe masks 215 define stripe-shaped openings. The 0.5 μ m-thick p-type GaN current block layers 114 doped with Mg are selectively grown on the top flat surface of the ridged portion of the 3 μ m-thick n-type GaN contact layer 103 by the metal organic chemical vapor deposition method using the silicon oxide stripe masks 215. Namely, the 0.5 μ m-thick p-type GaN current block layers 114 are selectively grown only on the stripe-shaped openings defined by silicon oxide stripe masks 215. The 0.5 μ m-thick p-type GaN current block layers 114 also have the hexagonal crystal structure. Since the 0.5 μ m-thick p-type GaN current block layers 114 are grown by a selective growth of the metal organic chemical vapor deposition method using dielectric stripe masks, the 0.5 μ m-thick p-type GaN current block layers 114 have highly flat and sloped inside walls. It is important that the 0.5 μ m-thick p-type GaN current block layers 114 having the hexagonal crystal structure are selectively grown by the metal organic chemical vapor deposition method using dielectric stripe masks on the 3 μ m-thick n-type GaN contact layer 103 having the hexagonal crystal structure. This results in the formation of the highly flat and sloped inside walls of the 0.5 μ m-thick p-type GaN current block layers 114. The highly flat and sloped inside walls of the 0.5 μ m-thick p-type GaN current block layers 114 cause current confinement. The used silicon oxide stripe masks 215 are removed by a florin acid solution. The 0.1 μ m-thick

n-type GaN cladding layer 115 doped with Si is then grown by the metal organic chemical vapor deposition so that the 0.1 μ m-thick n-type GaN cladding layer 115 extends on the top and flat surfaces and the above highly flat sloped inside walls of the 0.5 μ m-thick p-type GaN current block layers 114 as well as on an uncovered part of a top surface of the 3 μ m-thick n-type GaN contact layer 103. The 0.1 μ m-thick n-type GaN cladding layer 115 also has the hexagonal crystal structure. The 0.4 μ m-thick n-type $Al_{0.07}Ga_{0.93}N$ cladding layer 105 doped with Si is grown by the metal organic chemical vapor deposition on the 0.1 μ m-thick n-type GaN cladding layer 115 so that the 0.4 μ m-thick n-type $Al_{0.07}Ga_{0.93}N$ cladding layer 105 has the hexagonal crystal structure. The 0.1 μ m-thick n-type GaN optical guide layer 106 doped with Si is grown by the metal organic chemical vapor deposition on the 0.4 μ m-thick n-type $Al_{0.07}Ga_{0.93}N$ cladding layer 105 so that the 0.1 μ m-thick n-type GaN optical guide layer 106 has the hexagonal crystal structure. The multiple quantum well active layer 107 is grown by the metal organic chemical vapor deposition on the 0.1 μ m-thick n-type GaN optical guide layer 106, wherein the multiple quantum well active layer 107 comprises 7 periods of alternating 25Å-thick undoped $In_{0.2}Ga_{0.8}N$ quantum well layers and 50Å-thick undoped $In_{0.05}Ga_{0.95}N$ barrier layers. The 25Å-thick undoped $In_{0.2}Ga_{0.8}N$ quantum well layers and the 50Å-thick undoped $In_{0.05}Ga_{0.95}N$ barrier layers have the hexagonal crystal structure. The 200Å-thick p-type $Al_{0.2}Ga_{0.8}N$ layer 108 doped with Mg is grown by the metal organic chemical vapor deposition on the multiple quantum well active layer 107 so that the 200Å-thick p-type $Al_{0.2}Ga_{0.8}N$ layer 108 has the hexagonal crystal structure. The 200Å-thick p-type $Al_{0.2}Ga_{0.8}N$ layer 108 is capable of preventing dissociation of indium from the multiple quantum well active layer 107. The 0.1 μ m-thick p-type GaN optical guide layer 109 doped with Mg is grown by the metal organic chemical vapor deposition on the 200 Å-thick p-type $Al_{0.2}Ga_{0.8}N$ layer 108 so that the 0.1 μ m-thick p-type GaN optical guide layer 109 has the hexagonal crystal structure. The 0.4 μ m-thick p-type $Al_{0.07}Ga_{0.93}N$ cladding layer 110 doped with Mg is grown by the metal organic chemical vapor deposition on the 0.1 μ m-thick p-type GaN optical guide layer 109 so that the 0.4 μ m-thick p-type $Al_{0.07}Ga_{0.93}N$ cladding layer 110 has the hexagonal crystal structure. The 0.2 μ m-thick p-type GaN contact layer 111 doped with Mg is grown by the metal organic chemical vapor deposition on the 0.4 μ m-thick p-type $Al_{0.07}Ga_{0.93}N$ cladding layer 110 so that the 0.2 μ m-thick p-type GaN contact layer 111 has the hexagonal crystal structure. The nickel layer is formed on the top flat surface of the 0.2 μ m-thick p-type GaN contact layer 111 and a gold layer is then formed on the nickel layer thereby forming the p-electrode 112. A titanium layer is formed on the 3 μ m-thick n-type GaN contact layer 103 and an aluminum layer is then formed on the titanium layer.

Since the 0.5 μ m-thick p-type GaN current block

layers 114 have an opposite conductivity type to that of the 3 μ m-thick n-type GaN contact layer 103 and the 0.1 μ m-thick n-type GaN cladding layer 115 as well as the 0.4 μ m-thick n-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 105, then the 0.5 μ m-thick p-type GaN current block layers 114 are capable of blocking or guiding a current for current confinement. This current confinement allows a reduction in threshold current of the laser diode.

Since, further, the p-electrode 112 has a large contact area with the 0.2 μ m-thick p-type GaN contact layer 111, a contact resistance between the p-electrode 112 and the 0.2 μ m-thick p-type GaN contact layer 111 is small.

Furthermore, the above current confinement structure can be formed without use of the dry etching process.

Moreover, there are the differences in level of the 0.1 μ m-thick n-type GaN cladding layer 115, the 0.4 μ m-thick n-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 105, the 0.1 μ m-thick n-type GaN optical guide layer 106, the multiple quantum well active layer 107, the 200Å-thick p-type $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$ layer 108, the 0.1 μ m-thick p-type GaN optical guide layer 109 and the 0.411 m-thick p-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 110. This configuration forms that the cladding layers are positioned at the right and left sides of the active layer so that an optical control in the transverse mode can be made.

Since the gallium nitride based compound semiconductor layers having the hexagonal crystal structure are selectively formed on the (0001)-face of the gallium nitride layer, then the gallium nitride based compound semiconductor layers are almost not grown in the [1-100] direction.

Namely, the p-type gallium nitride current block layers 114 having the hexagonal structure are selectively grown on the (0001)-face of the n-type gallium nitride layer 103 having the hexagonal crystal structure by use of the dielectric stripe masks arranged in a longitudinal direction along the [11-20] direction so that no extending portion over the dielectric stripe masks is formed.

In the above gallium nitride based compound semiconductor laser diode, an optical waveguide is formed in a direction along the [11-20] direction of the crystal structure. It is difficult to cleave the semiconductor wafer in the [11-20] direction. This means it difficult to form the reflective faces of resonator in the laser diode by the cleaving method. For this reason, it is necessary to form the reflective faces of resonator in the laser diode by other method such as dry etching.

As a modification, the optical waveguide may be formed in a direction tilted from the [11-20] direction of the crystal structure by an angle in the range of ± 5 degrees. Even if the optical waveguide is formed in a direction tilted from the [11-20] direction of the crystal structure by an angle over the range of ± 5 degrees, then there is no problem unless the semiconductor layer is allowed to be selectively grown in the [11-20] direction. In the later case, however, it is necessary that the die-

lectric strip masks are almost the same in thickness as the current block layers.

Whereas in the above embodiment the semiconductor layers having the hexagonal crystal structure are grown on the (0001)-face of the sapphire substrate, it is also possible to grow the semiconductor layers having the hexagonal crystal structure on the (11-20)-face of the sapphire substrate.

Further, in place of the (0001)-face sapphire substrate and the (11-20)-face sapphire substrate, silicon oxide substrates with the (0001)-face or the (11-20)-face are available. Furthermore, MgAl_2O_4 substrates with the (0001)-face or the (11-20)-face are also available. Gallium nitride substrates with the (0001)-face or the (11-20)-face are still further available. The sapphire substrate, silicon oxide substrate, MgAl_2O_4 substrate, and gallium nitride substrate having other faces than the (0001)-face or the (11-20)-face are also available.

The above present invention can be applied not only to the gallium nitride based laser diode as illustrated in the drawings but also other gallium nitride based laser diodes which are different in thickness of layer, composition of layer, doping concentration of layer, material of electrode, material of dielectric stripe masks, depth of dry etching, and width of stripe of the dielectric stripe masks.

Although in the above embodiment, the individual semiconductor layers have surfaces of the (0001)-face, the surfaces of the individual semiconductor layers may be tilted from the (0001)-face by an angle in the range of ± 5 degrees.

SECOND EMBODIMENT:

A second embodiment according to the present invention will be described with reference to FIGS. 5 and 6. FIG. 5 is a fragmentary cross sectional elevation view illustrative of a novel gallium nitride based compound semiconductor laser having a current block layer structure for a current confinement in a second embodiment according to the present invention. FIG. 6 is a fragmentary cross sectional elevation view illustrative of a novel gallium nitride based compound semiconductor laser in a selective growth process by a metal organic chemical vapor deposition method involved in a fabrication method thereof.

The novel gallium nitride based compound semiconductor laser is formed on a (0001)-face sapphire substrate 101. All of compound semiconductor layers in the novel gallium nitride based compound semiconductor laser have hexagonal crystal structures. The structure of the novel gallium nitride based compound semiconductor laser is as follows. A 300Å-thick undoped GaN buffer layer 102 is provided on a (0001)-face sapphire substrate 101. The 300Å-thick undoped GaN buffer layer 102 has a hexagonal crystal structure. A 3 μ m-thick n-type GaN contact layer 103 doped with Si is provided on an entire surface of the 300Å-thick undoped GaN buffer layer 102. The 3 μ m-thick n-type GaN con-

tact layer 103 has a hexagonal crystal structure. The 3 μ m-thick n-type GaN contact layer 103 has a ridged portion and recess portions. A top surface of the ridged portion of the 3 μ m-thick n-type GaN contact layer 103 is a flat surface. Upper surfaces of the recess portions of the 3 μ m-thick n-type GaN contact layer 103 are also flat surfaces. Further, 0.5 μ m-thick p-type GaN current block layers 114 doped with Mg are selectively provided on the top flat surface of the ridged portion of the 3 μ m-thick n-type GaN contact layer 103. The 0.5 μ m-thick p-type GaN current block layers 114 also have the hexagonal crystal structure. As will be described later, the 0.5 μ m-thick p-type GaN current block layers 114 are formed by a selective growth of a metal organic chemical vapor deposition method using dielectric stripe masks, for which reason the 0.5 μ m-thick p-type GaN current block layers 114 have highly flat and sloped inside walls. It is important that the 0.5 μ m-thick p-type GaN current block layers 114 having the hexagonal crystal structure are selectively grown by the metal organic chemical vapor deposition method using dielectric stripe masks on the 3 μ m-thick n-type GaN contact layer 103 having the hexagonal crystal structure. This results in the formation of the highly flat and sloped inside walls of the 0.5 μ m-thick p-type GaN current block layers 114. The highly flat and sloped inside walls of the 0.5 μ m-thick p-type GaN current block layers 114 cause current confinement as will be described later. A 0.5 μ m-thick n-type GaN cladding layer 115 doped with Si is then selectively provided which extends on the above highly flat sloped inside walls of the 0.5 μ m-thick p-type GaN current block layers 114 as well as on an uncovered part of a top surface of the 3 μ m-thick n-type GaN contact layer 103 whilst the 0.5 μ m-thick n-type GaN cladding layer 115 does not extend over the top surfaces of the 0.5 μ m-thick p-type GaN current block layers 114 so that the top surface of the 0.5 μ m-thick n-type GaN cladding layer 115 has the same level as the top surfaces of the 0.5 μ m-thick p-type GaN current block layers 114, whereby a flat top surface is formed. The 0.5 μ m-thick n-type GaN cladding layer 115 has the hexagonal crystal structure. A 0.4 μ m-thick n-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 105 doped with Si is provided on the flat and leveled top surfaces of the 0.5 μ m-thick n-type GaN cladding layer 115 and the 0.5 μ m-thick p-type GaN current block layers 114. The 0.4 μ m-thick n-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 105 is flat layer or has no difference in level. The 0.4 μ m-thick n-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 105 has the hexagonal crystal structure. A 0.1 μ m-thick n-type GaN optical guide layer 106 doped with Si is provided on the 0.4 μ m-thick n-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 105. The 0.1 μ m-thick n-type GaN optical guide layer 106 has the hexagonal crystal structure. A multiple quantum well active layer 107 is provided on the 0.1 μ m-thick n-type GaN optical guide layer 106. The multiple quantum well active layer 107 comprises 7 periods of alternating 25 \AA -thick undoped $\text{In}_{0.2}\text{Ga}_{0.8}\text{N}$ quantum well layers and

5 50 \AA -thick undoped $\text{In}_{0.05}\text{Ga}_{0.95}\text{N}$ barrier layers. The 25 \AA -thick undoped $\text{In}_{0.2}\text{Ga}_{0.8}\text{N}$ quantum well layers have the hexagonal crystal structure. The 50 \AA -thick undoped $\text{In}_{0.05}\text{Ga}_{0.95}\text{N}$ barrier layers have the hexagonal crystal structure. A 200 \AA -thick p-type $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$ layer 108 doped with Mg is provided on the multiple quantum well active layer 107. The 200 \AA -thick p-type $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$ layer 108 has the hexagonal crystal structure. A 0.1 μ m-thick p-type GaN optical guide layer 109 doped with Mg is provided on the 200 \AA -thick p-type $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$ layer 108. The 0.1 μ m-thick p-type GaN optical guide layer 109 has the hexagonal crystal structure. A 0.4 μ m-thick p-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 110 doped with Mg is provided on the 0.1 μ m-thick p-type GaN optical guide layer 109. The 0.4 μ m-thick p-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 110 has the hexagonal crystal structure. There are no differences in level of the 0.4 μ m-thick n-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 105, the 0.1 μ m-thick n-type GaN optical guide layer 106, the multiple quantum well active layer 107, the 200 \AA -thick p-type $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$ layer 108, the 0.1 μ m-thick p-type GaN optical guide layer 109 and the 0.4 μ m-thick p-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 110. A 0.2 μ m-thick p-type GaN contact layer 111 doped with Mg is provided on the 0.4 μ m-thick p-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 110. A top surface of the 0.2 μ m-thick p-type GaN contact layer 111 is flat. The 0.2 μ m-thick p-type GaN contact layer 111 has the hexagonal crystal structure. A p-electrode 112 is provided on the top flat surface of the 0.2 μ m-thick p-type GaN contact layer 111. The p-electrode 112 comprises a nickel layer laminated on the top flat surface of the 0.2 μ m-thick p-type GaN contact layer 111 and a gold layer laminated on the nickel layer. An n-electrode 113 is provided on the recessed surface of the 3 μ m-thick n-type GaN contact layer 103. The n-electrode 113 comprises a titanium layer laminated on the 3 μ m-thick n-type GaN contact layer 103 and an aluminum layer laminated on the titanium layer.

40 As described above, since the 0.5 μ m-thick p-type GaN current block layers 114 have an opposite conductivity type to that of the 3 μ m-thick n-type GaN contact layer 103 and the 0.5 μ m-thick n-type GaN cladding layer 115 as well as the 0.4 μ m-thick n-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 105, then the 0.5 μ m-thick p-type GaN current block layers 114 are capable of blocking or guiding a current for current confinement. This current confinement allows a reduction in threshold current of the laser diode.

45 The above laser diode is formed as follows. The 300 \AA -thick undoped GaN buffer layer 102 is grown by a metal organic chemical vapor deposition method at a low temperature on the flat (0001)-face sapphire substrate 101 so that the 300 \AA -thick undoped GaN buffer layer 102 has a hexagonal crystal structure. The 3 μ m-thick n-type GaN contact layer 103 doped with Si is grown by a metal organic chemical vapor deposition method on an entire surface of the 300 \AA -thick undoped GaN buffer layer 102 so that the 3 μ m-thick n-type GaN

contact layer 103 has a hexagonal crystal structure. Silicon oxide stripe masks 215 having a width of 1 micrometer are arranged in a [11-20] direction of the hexagonal crystal structure of the 3 μ m-thick n-type GaN contact layer 103. The silicon oxide stripe masks 215 define stripe-shaped openings. The 0.5 μ m-thick p-type GaN current block layers 114 doped with Mg are selectively grown on the top flat surface of the ridged portion of the 3 μ m-thick n-type GaN contact layer 103 by the metal organic chemical vapor deposition method using the silicon oxide stripe masks 215. Namely, the 0.5 μ m-thick p-type GaN current block layers 114 are selectively grown only on the stripe-shaped openings defined by silicon oxide stripe masks 215. The 0.5 μ m-thick p-type GaN current block layers 114 also have the hexagonal crystal structure. Since the 0.5 μ m-thick p-type GaN current block layers 114 are grown by a selective growth of the metal organic chemical vapor deposition method using dielectric stripe masks, the 0.5 μ m-thick p-type GaN current block layers 114 have highly flat and sloped inside walls. It is important that the 0.5 μ m-thick p-type GaN current block layers 114 having the hexagonal crystal structure are selectively grown by the metal organic chemical vapor deposition method using dielectric stripe masks on the 3 μ m-thick n-type GaN contact layer 103 having the hexagonal crystal structure. This results in the formation of the highly flat and sloped inside walls of the 0.5 μ m-thick p-type GaN current block layers 114. The highly flat and sloped inside walls of the 0.5 μ m-thick p-type GaN current block layers 114 cause current confinement. The used silicon oxide stripe masks 215 are removed by a florin acid solution. Other silicon oxide stripe masks not illustrated are then provided on the top surfaces of the 0.5 μ m-thick p-type GaN current block layers 114. The 0.1 μ m-thick n-type GaN cladding layer 115 doped with Si is then grown by the metal organic chemical vapor deposition using the other silicon oxide stripe masks so that the 0.5 μ m-thick n-type GaN cladding layer 115 extends on the above highly flat sloped inside walls of the 0.5 μ m-thick p-type GaN current block layers 114 as well as on an uncovered part of a top surface of the 3 μ m-thick n-type GaN contact layer 103. However, the 0.5 μ m-thick n-type GaN cladding layer 115 does not extend over the top surfaces of the 0.5 μ m-thick p-type GaN current block layers 114. Namely, the top surface of the 0.5 μ m-thick n-type GaN cladding layer 115 has the same level as the top surfaces of the 0.5 μ m-thick p-type GaN current block layers 114. The 0.5 μ m-thick n-type GaN cladding layer 115 also has the hexagonal crystal structure. The used other silicon oxide stripe masks are removed. The 0.4 μ m-thick n-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 105 doped with Si is grown by the metal organic chemical vapor deposition on the 0.1 μ m-thick n-type GaN cladding layer 115 so that the 0.4 μ m-thick n-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 105 has the hexagonal crystal structure. The 0.1 μ m-thick n-type GaN optical guide layer 106 doped with Si is grown by the metal organic chemical vapor deposition

deposition on the 0.4 μ m-thick n-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 105 so that the 0.1 μ m-thick n-type GaN optical guide layer 106 has the hexagonal crystal structure. The multiple quantum well active layer 107 is grown by the metal organic chemical vapor deposition on the 0.1 μ m-thick n-type GaN optical guide layer 106, wherein the multiple quantum well active layer 107 comprises 7 periods of alternating 25 \AA -thick undoped $\text{In}_{0.2}\text{Ga}_{0.8}\text{N}$ quantum well layers and 50 \AA -thick undoped $\text{In}_{0.05}\text{Ga}_{0.95}\text{N}$ barrier layers. The 25 \AA -thick undoped $\text{In}_{0.2}\text{Ga}_{0.8}\text{N}$ quantum well layers and the 50 \AA -thick undoped $\text{In}_{0.05}\text{Ga}_{0.95}\text{N}$ barrier layers have the hexagonal crystal structure. The 200 \AA -thick p-type $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$ layer 108 doped with Mg is grown by the metal organic chemical vapor deposition on the multiple quantum well active layer 107 so that the 200 \AA -thick p-type $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$ layer 108 has the hexagonal crystal structure. The 200 \AA -thick p-type $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$ layer 108 is capable of preventing dissociation of indium from the multiple quantum well active layer 107. The 0.1 μ m-thick p-type GaN optical guide layer 109 doped with Mg is grown by the metal organic chemical vapor deposition on the 200 \AA -thick p-type $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$ layer 108 so that the 0.1 μ m-thick p-type GaN optical guide layer 109 has the hexagonal crystal structure. The 0.4 μ m-thick p-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 110 doped with Mg is grown by the metal organic chemical vapor deposition on the 0.1 μ m-thick p-type GaN optical guide layer 109 so that the 0.4 μ m-thick p-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 110 has the hexagonal crystal structure. The 0.2 μ m-thick p-type GaN contact layer 111 doped with Mg is grown by the metal organic chemical vapor deposition on the 0.4 μ m-thick p-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 110 so that the 0.2 μ m-thick p-type GaN contact layer 111 has the hexagonal crystal structure. The nickel layer is formed on the top flat surface of the 0.2 μ m-thick p-type GaN contact layer 111 and a gold layer is then formed on the nickel layer thereby forming the p-electrode 112. A titanium layer is formed on the 3 μ m-thick n-type GaN contact layer 103 and an aluminum layer is then formed on the titanium layer.

Since the 0.5 μ m-thick p-type GaN current block layers 114 have an opposite conductivity type to that of the 3 μ m-thick n-type GaN contact layer 103 and the 0.5 μ m-thick n-type GaN cladding layer 115 as well as the 0.4 μ m-thick n-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 105, then the 0.5 μ m-thick p-type GaN current block layers 114 are capable of blocking or guiding a current for current confinement. This current confinement allows a reduction in threshold current of the laser diode.

Since, further, the p-electrode 112 has a large contact area with the 0.2 μ m-thick p-type GaN contact layer 111, a contact resistance between the p-electrode 112 and the 0.2 μ m-thick p-type GaN contact layer 111 is small.

Furthermore, the above current confinement structure can be formed without use of the dry etching process.

Moreover, the multiple quantum well active layer 107 is formed on the flat surface. This results in no possibility of compositional modification or no variation in composition over position of the active layer.

Since the gallium nitride based compound semiconductor layers having the hexagonal crystal structure are selectively formed on the (0001)-face of the gallium nitride layer, then the gallium nitride based compound semiconductor layers are almost not grown in the [1-100] direction.

Namely, the p-type gallium nitride current block layers 114 having the hexagonal structure are selectively grown on the (0001)-face of the n-type gallium nitride layer 103 having the hexagonal crystal structure by use of the dielectric stripe masks arranged in a longitudinal direction along the [11-20] direction so that no extending portion over the dielectric stripe masks is formed.

In the above gallium nitride based compound semiconductor laser diode, an optical waveguide is formed in a direction along the [11-20] direction of the crystal structure. It is difficult to cleave the semiconductor wafer in the [11-20] direction. This means it difficult to form the reflective faces of resonator in the laser diode by the cleaving method. For this reason, it is necessary to form the reflective faces of resonator in the laser diode by other method such as dry etching.

As a modification, the optical waveguide may be formed in a direction tilted from the [11-20] direction of the crystal structure by an angle in the range of ± 5 degrees. Even if the optical waveguide is formed in a direction tilted from the [11-20] direction of the crystal structure by an angle over the range of ± 5 degrees, then there is no problem unless the semiconductor layer is allowed to be selectively grown in the [11-20] direction. In the later case, however, it is necessary that the dielectric strip masks are almost the same in thickness as the current block layers.

Whereas in the above embodiment the semiconductor layers having the hexagonal crystal structure are grown on the (0001)-face of the sapphire substrate, it is also possible to grow the semiconductor layers having the hexagonal crystal structure on the (11-20)-face of the sapphire substrate.

Further, in place of the (0001)-face sapphire substrate and the (11-20)-face sapphire substrate, silicon oxide substrates with the (0001)-face or the (11-20)-face are available. Furthermore, $MgAl_2O_4$ substrates with the (0001)-face or the (11-20)-face are also available. Gallium nitride substrates with the (0001)-face or the (11-20)-face are still further available. The sapphire substrate, silicon oxide substrate, $MgAl_2O_4$ substrate, and gallium nitride substrate having other faces than the (0001)-face or the (11-20)-face are also available.

The above present invention can be applied not only to the gallium nitride based laser diode as illustrated in the drawings but also other gallium nitride based laser diodes which are different in thickness of layer, composition of layer, doping concentration of layer, material of

electrode, material of dielectric stripe masks, depth of dry etching, and width of stripe of the dielectric stripe masks.

Although in the above embodiment, the individual semiconductor layers have surfaces of the (0001)-face, the surfaces of the individual semiconductor layers may be tilted from the (0001)-face by an angle in the range of ± 5 degrees.

THIRD EMBODIMENT:

A third embodiment according to the present invention will be described with reference to FIGS. 7 and 8. FIG. 7 is a fragmentary cross sectional elevation view illustrative of a novel gallium nitride based compound semiconductor laser having a current block layer structure for a current confinement in a third embodiment according to the present invention. FIG. 8 is a fragmentary cross sectional elevation view illustrative of a novel gallium nitride based compound semiconductor laser in a selective growth process by a metal organic chemical vapor deposition method involved in a fabrication method thereof.

The novel gallium nitride based compound semiconductor laser is formed on a (11-20)-face sapphire substrate 201. All of compound semiconductor layers in the novel gallium nitride based compound semiconductor laser have hexagonal crystal structures. The structure of the novel gallium nitride based compound semiconductor laser is as follows. A 300Å-thick undoped GaN buffer layer 102 is provided on a (11-20)-face sapphire substrate 201. The 300Å-thick undoped GaN buffer layer 102 has a hexagonal crystal structure. A 3 μ m-thick n-type GaN contact layer 103 doped with Si is provided on an entire surface of the 300Å-thick undoped GaN buffer layer 102. The 3 μ m-thick n-type GaN contact layer 103 has a hexagonal crystal structure. The 3 μ m-thick n-type GaN contact layer 103 has a ridged portion and recess portions. A top surface of the ridged portion of the 3 μ m-thick n-type GaN contact layer 103 is a flat surface. Upper surfaces of the recess portions of the 3 μ m-thick n-type GaN contact layer 103 are also flat surfaces. A 0.1 μ m-thick n-type $In_{0.05}Ga_{0.95}N$ layer 104 doped with Si is provided on the top flat surface of the ridged portion of the 3 μ m-thick n-type GaN contact layer 103. The 0.1 μ m-thick n-type $In_{0.05}Ga_{0.95}N$ layer 104 is capable of preventing crack in the compound semiconductor. A 0.4 μ m-thick n-type $Al_{0.07}Ga_{0.93}N$ cladding layer 105 doped with Si is provided on the 0.1 μ m-thick n-type $In_{0.05}Ga_{0.95}N$ layer 104. The 0.4 μ m-thick n-type $Al_{0.07}Ga_{0.93}N$ cladding layer 105 has the hexagonal crystal structure. A 0.1 μ m-thick n-type GaN optical guide layer 106 doped with Si is provided on the 0.4 μ m-thick n-type $Al_{0.07}Ga_{0.93}N$ cladding layer 105. The 0.1 μ m-thick n-type GaN optical guide layer 106 has the hexagonal crystal structure. A multiple quantum well active layer 107 is provided on the 0.1 μ m-thick n-type GaN optical guide layer 106. The multiple quantum well active layer 107 comprises 7 periods of alternating

25Å-thick undoped $\text{In}_{0.2}\text{Ga}_{0.8}\text{N}$ quantum well layers and 50Å-thick undoped $\text{In}_{0.05}\text{Ga}_{0.95}\text{N}$ barrier layers. The 25 Å-thick undoped $\text{In}_{0.2}\text{Ga}_{0.8}\text{N}$ quantum well layers have the hexagonal crystal structure. The 50Å-thick undoped $\text{In}_{0.05}\text{Ga}_{0.95}\text{N}$ barrier layers have the hexagonal crystal structure. A 200Å-thick p-type $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$ layer 108 doped with Mg is provided on the multiple quantum well active layer 107. The 200Å-thick p-type $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$ layer 108 has the hexagonal crystal structure. A 0.1 μ m-thick p-type GaN optical guide layer 109 doped with Mg is provided on the 200Å-thick p-type $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$ layer 108. The 0.1 μ m-thick p-type GaN optical guide layer 109 has the hexagonal crystal structure. A 0.4 μ m-thick p-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 110 doped with Mg is provided on the 0.1 μ m-thick p-type GaN optical guide layer 109. The 0.4 μ m-thick p-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 110 has the hexagonal crystal structure. A 0.2 μ m-thick p-type GaN layer 214 doped with Mg is provided on the 0.4 μ m-thick p-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 110. The 0.2 μ m-thick p-type GaN layer 214 has the hexagonal crystal structure. Further, 2000Å-thick silicon oxide stripe masks 215 are provided so that a longitudinal direction of the 2000Å-thick silicon oxide stripe masks 215 is parallel to the [1-100] direction of the hexagonal crystal structure. The 2000Å-thick silicon oxide stripe masks 215 defines a stripe-shaped opening with a width of 5 μ m. A 0.3 μ m-thick p-type GaN contact layer 111 doped with Mg is selectively provided on the stripe-shaped opening of the 2000Å-thick silicon oxide stripe masks 215 over the 0.2 μ m-thick p-type GaN layer 214 and also on parts adjacent to the stripe-shaped opening of the 2000Å-thick silicon oxide stripe masks 215. Namely, the 0.3 μ m-thick p-type GaN contact layer 111 is selectively grown by use of the 2000Å-thick silicon oxide stripe masks 215 so that the 0.3 μ m-thick p-type GaN contact layer 111 has a ridge-shape in cross sectional view and also has sloped and highly flat side walls. The 0.3 μ m-thick p-type GaN contact layer 111 has the hexagonal crystal structure. A p-electrode 112 is provided which extends on the top surface and the highly flat side walls of the 0.3 μ m-thick p-type GaN contact layer 111 as well as over parts of the 2000 Å-thick silicon oxide stripe masks 215. The p-electrode 112 comprises a nickel layer laminated on the top surface and the highly flat side walls of the 0.3 μ m-thick p-type GaN contact layer 111 and a gold layer laminated on the nickel layer. An n-electrode 113 is provided on the recessed surface of the 3 μ m-thick n-type GaN contact layer 103. The n-electrode 113 comprises a titanium layer laminated on the 3 μ m-thick n-type GaN contact layer 103 and an aluminum layer laminated on the titanium layer.

In this embodiment, the 2000Å-thick silicon oxide stripe masks 215 and the ridge-shaped 0.3 μ m-thick p-type GaN contact layer 111 serve for current confinement. This current confinement allows a reduction in threshold current of the laser diode.

The above laser diode is formed as follows. The 300Å-thick undoped GaN buffer layer 102 is grown by

a metal organic chemical vapor deposition method at a low temperature on the flat (11-20)-face sapphire substrate 201 so that the 300Å-thick undoped GaN buffer layer 102 has a hexagonal crystal structure. The 3 μ m-thick n-type GaN contact layer 103 doped with Si is grown by a metal organic chemical vapor deposition method on an entire surface of the 300Å-thick undoped GaN buffer layer 102 so that the 3 μ m-thick n-type GaN contact layer 103 has a hexagonal crystal structure. The 0.1 μ m-thick n-type $\text{In}_{0.05}\text{Ga}_{0.95}\text{N}$ layer 104 doped with Si is grown by the metal organic chemical vapor deposition on the top surface of the ridged portion of the 3 μ m-thick n-type GaN contact layer 103 so that the 0.1 μ m-thick n-type $\text{In}_{0.05}\text{Ga}_{0.95}\text{N}$ layer 104 has a hexagonal crystal structure. The 0.4 μ m-thick n-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 105 doped with Si is grown by the metal organic chemical vapor deposition on the 0.1 μ m-thick n-type $\text{In}_{0.05}\text{Ga}_{0.95}\text{N}$ layer 104 so that the 0.4 μ m-thick n-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 105 has the hexagonal crystal structure. The 0.1 μ m-thick n-type GaN optical guide layer 106 doped with Si is grown by the metal organic chemical vapor deposition on the 0.4 μ m-thick n-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 105 so that the 0.1 μ m-thick n-type GaN optical guide layer 106 has the hexagonal crystal structure. The multiple quantum well active layer 107 is grown by the metal organic chemical vapor deposition on the 0.1 μ m-thick n-type GaN optical guide layer 106, wherein the multiple quantum well active layer 107 comprises 7 periods of alternating 25Å-thick undoped $\text{In}_{0.2}\text{Ga}_{0.8}\text{N}$ quantum well layers and 50Å-thick undoped $\text{In}_{0.05}\text{Ga}_{0.95}\text{N}$ barrier layers. The 25Å-thick undoped $\text{In}_{0.2}\text{Ga}_{0.8}\text{N}$ quantum well layers and the 50Å-thick undoped $\text{In}_{0.05}\text{Ga}_{0.95}\text{N}$ barrier layers have the hexagonal crystal structure.

The 200Å-thick p-type $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$ layer 108 doped with Mg is grown by the metal organic chemical vapor deposition on the multiple quantum well active layer 107 so that the 200Å-thick p-type $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$ layer 108 has the hexagonal crystal structure. The 200Å-thick p-type $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$ layer 108 is capable of preventing dissociation of indium from the multiple quantum well active layer 107. The 0.1 μ m-thick p-type GaN optical guide layer 109 doped with Mg is grown by the metal organic chemical vapor deposition on the 200Å-thick p-type $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$ layer 108 so that the 0.1 μ m-thick p-type GaN optical guide layer 109 has the hexagonal crystal structure. The 0.4 μ m-thick p-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 110 doped with Mg is grown by the metal organic chemical vapor deposition on the 0.1 μ m-thick p-type GaN optical guide layer 109 so that the 0.4 μ m-thick p-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 110 has the hexagonal crystal structure. The 0.2 μ m-thick p-type GaN layer 214 is grown by the metal organic chemical vapor deposition on the 0.4 μ m-thick p-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 110 so that the 0.2 μ m-thick p-type GaN layer 214 has the hexagonal crystal structure. Further, 2000Å-thick silicon oxide stripe masks 215 are arranged on the 0.2 μ m-thick p-type GaN layer 214

so that a longitudinal direction of the 2000Å-thick silicon oxide stripe masks 215 is parallel to the [1-100] direction of the hexagonal crystal structure. The 2000Å-thick silicon oxide stripe masks 215 defines a stripe-shaped opening with a width of 5 μ m. A 0.3 μ m-thick p-type GaN contact layer 111 doped with Mg is selectively grown by the metal organic chemical vapor deposition using the 2000Å-thick silicon oxide stripe masks 215 on the stripe-shaped opening of the 2000Å-thick silicon oxide stripe masks 215 over the 0.2 μ m-thick p-type GaN layer 214 and also on parts adjacent to the stripe-shaped opening of the 2000Å-thick silicon oxide stripe masks 215. The 0.3 μ m-thick p-type GaN contact layer 111 has a ridge-shape in cross sectional view and also has sloped and highly flat side walls. The 0.3 μ m-thick p-type GaN contact layer 111 has the hexagonal crystal structure. The nickel layer is formed on the top surface and the sloped and highly flat side walls of the 0.3 μ m-thick p-type GaN contact layer 111 as well as parts of the 2000Å-thick silicon oxide stripe masks 215. A gold layer is then formed on the nickel layer thereby forming the p-electrode 112. A titanium layer is formed on the 3 μ m-thick n-type GaN contact layer 103 and an aluminum layer is then formed on the titanium layer.

Since the 2000Å-thick silicon oxide stripe masks 215 and the ridge-shaped 0.3 μ m-thick p-type GaN contact layer 111 serve for current confinement. This current confinement allows a reduction in threshold current of the laser diode.

Since, further, the p-electrode 112 has a large contact area with the 0.3 μ m-thick p-type GaN contact layer 111, a contact resistance between the p-electrode 112 and the 0.3 μ m-thick p-type GaN contact layer 111 is small.

Furthermore, the above current confinement structure can be formed without use of the dry etching process.

Moreover, the multiple quantum well active layer 107 is formed on the flat surface. This results in no possibility of compositional modification or no variation in composition over position of the active layer.

Since the gallium nitride based compound semiconductor layers having the hexagonal crystal structure are selectively formed on the (0001)-face of the gallium nitride layer, then a growth rate of gallium nitride in the [11-20] direction is almost the same as that in the [0001] direction.

Namely, the p-type gallium nitride contact layer 111 having the hexagonal structure are selectively grown on the (0001)-face of the p-type gallium nitride layer 214 having the hexagonal crystal structure by use of the dielectric stripe masks arranged in a longitudinal direction along the [1-100] direction so that the p-type gallium nitride contact layer 111 has extending portions over the dielectric stripe masks. This leads to a large contact area between the p-type gallium nitride contact layer 111 and the p-electrode 112 thereby reduction in contact resistance between the p-type gallium nitride contact layer

111 and the p-electrode 112.

In the above gallium nitride based compound semiconductor laser diode, an optical waveguide is formed in a direction along the [1-100] direction of the crystal structure. It is possible to cleave the semiconductor wafer in the [1-100] direction. This means it possible to form the reflective faces of resonator in the laser diode by the cleaving method.

Moreover, the p-type gallium nitride contact layer 111 are positioned between the 2000Å-thick silicon oxide stripe masks 215 so that an optical control in the transverse mode can be made.

As a modification, the optical waveguide may be formed in a direction tilted from the [1-100] direction of the crystal structure by an angle in the range of ± 5 degrees. Even if the optical waveguide is formed in a direction tilted from the [1-100] direction of the crystal structure by an angle over the range of ± 5 degrees, then there is no further problem to a reduction in contact area between the p-electrode and the contact layer.

Whereas in the above embodiment the semiconductor layers having the hexagonal crystal structure are grown on the (11-20)-face of the sapphire substrate, it is also possible to grow the semiconductor layers having the hexagonal crystal structure on the (0001)-face of the sapphire substrate.

Further, in place of the (0001)-face sapphire substrate and the (11-20)-face sapphire substrate, silicon oxide substrates with the (0001)-face or the (11-20)-face are available. Furthermore, $MgAl_2O_4$ substrates with the (0001)-face or the (11-20)-face are also available. Gallium nitride substrates with the (0001)-face or the (11-20)-face are still further available. The sapphire substrate, silicon oxide substrate, $MgAl_2O_4$ substrate, and gallium nitride substrate having other faces than the (0001)-face or the (11-20)-face are also available.

The above present invention can be applied not only to the gallium nitride based laser diode as illustrated in the drawings but also other gallium nitride based laser diodes which are different in thickness of layer, composition of layer, doping concentration of layer, material of electrode, material of dielectric stripe masks, depth of dry etching, and width of stripe of the dielectric stripe masks.

Although in the above embodiment, the individual semiconductor layers have surfaces of the (0001)-face, the surfaces of the individual semiconductor layers may be tilted from the (0001)-face by an angle in the range of ± 5 degrees.

50 FOURTH EMBODIMENT:

A fourth embodiment according to the present invention will be described with reference to FIGS. 9 and 10. FIG. 9 is a fragmentary cross sectional elevation view illustrative of a novel gallium nitride based compound semiconductor laser having a current block layer structure for a current confinement in a fourth embodiment according to the present invention. FIG. 10 is a

fragmentary cross sectional elevation view illustrative of a novel gallium nitride based compound semiconductor laser in a selective growth process by a metal organic chemical vapor deposition method involved in a fabrication method thereof.

The novel gallium nitride based compound semiconductor laser is formed on a (0001)-face sapphire substrate 101. All of compound semiconductor layers in the novel gallium nitride based compound semiconductor laser have hexagonal crystal structures. The structure of the novel gallium nitride based compound semiconductor laser is as follows. A 300Å-thick undoped GaN buffer layer 102 is provided on a (0001)-face sapphire substrate 101. The 300Å-thick undoped GaN buffer layer 102 has a hexagonal crystal structure. A 3 μ m-thick n-type GaN contact layer 103 doped with Si is provided on an entire surface of the 300Å-thick undoped GaN buffer layer 102. The 3 μ m-thick n-type GaN contact layer 103 has a hexagonal crystal structure. The 3 μ m-thick n-type GaN contact layer 103 has a ridged portion and recess portions. A top surface of the ridged portion of the 3 μ m-thick n-type GaN contact layer 103 is a flat surface. Upper surfaces of the recess portions of the 3 μ m-thick n-type GaN contact layer 103 are also flat surfaces. A 0.1 μ m-thick n-type $In_{0.05}Ga_{0.95}N$ layer 104 doped with Si is provided on the top flat surface of the ridged portion of the 3 μ m-thick n-type GaN contact layer 103. The 0.1 μ m-thick n-type $In_{0.05}Ga_{0.95}N$ layer 104 is capable of preventing crack in the compound semiconductor. A 0.4 μ m-thick n-type $Al_{0.07}Ga_{0.93}N$ cladding layer 105 doped with Si is provided on the 0.1 μ m-thick n-type $In_{0.05}Ga_{0.95}N$ layer 104. The 0.4 μ m-thick n-type $Al_{0.07}Ga_{0.93}N$ cladding layer 105 has the hexagonal crystal structure. A 0.1 μ m-thick n-type GaN optical guide layer 106 doped with Si is provided on the 0.4 μ m-thick n-type $Al_{0.07}Ga_{0.93}N$ cladding layer 105. The 0.1 μ m-thick n-type GaN optical guide layer 106 has the hexagonal crystal structure. A multiple quantum well active layer 107 is provided on the 0.1 μ m-thick n-type GaN optical guide layer 106. The multiple quantum well active layer 107 comprises 7 periods of alternating 25Å-thick undoped $In_{0.2}Ga_{0.8}N$ quantum well layers and 50Å-thick undoped $In_{0.05}Ga_{0.95}N$ barrier layers. The 25 Å-thick undoped $In_{0.2}Ga_{0.8}N$ quantum well layers have the hexagonal crystal structure. The 50Å-thick undoped $In_{0.05}Ga_{0.95}N$ barrier layers have the hexagonal crystal structure. A 200Å-thick p-type $Al_{0.2}Ga_{0.8}N$ layer 108 doped with Mg is provided on the multiple quantum well active layer 107. The 200Å-thick p-type $Al_{0.2}Ga_{0.8}N$ layer 108 has the hexagonal crystal structure. A 0.1 μ m-thick p-type GaN optical guide layer 109 doped with Mg is provided on the 200Å-thick p-type $Al_{0.2}Ga_{0.8}N$ layer 108. The 0.1 μ m-thick p-type GaN optical guide layer 109 has the hexagonal crystal structure. A 0.4 μ m-thick p-type $Al_{0.07}Ga_{0.93}N$ cladding layer 110 doped with Mg is provided on the 0.1 μ m-thick p-type GaN optical guide layer 109. The 0.4 μ m-thick p-type $Al_{0.07}Ga_{0.93}N$ cladding layer 110 has the hexagonal

crystal structure. A 0.2 μ m-thick p-type GaN layer 214 doped with Mg is provided on the 0.4 μ m-thick p-type $Al_{0.07}Ga_{0.93}N$ cladding layer 110. The 0.2 μ m-thick p-type GaN layer 214 has the hexagonal crystal structure.

5 Further, 0.5 μ m-thick n-type GaN current block layers 315 doped with Si are selectively provided on the 0.2 μ m-thick p-type GaN layer 214. The 0.5 μ m-thick n-type GaN current block layers 315 also have the hexagonal crystal structure. As will be described later, the 0.5 μ m-thick n-type GaN current block layers 315 are formed by a selective growth of a metal organic chemical vapor deposition method using dielectric stripe masks, for which reason the 0.5 μ m-thick n-type GaN current block layers 315 have highly flat and sloped inside walls. It is 10 important that the 0.5 μ m-thick n-type GaN current block layers 315 having the hexagonal crystal structure are selectively grown by the metal organic chemical vapor deposition method using dielectric stripe masks on the 0.2 μ m-thick p-type GaN layer 214 having the hexagonal crystal structure. This results in the formation of the highly flat and sloped inside walls of the 0.5 μ m-thick n-type GaN current block layers 315. The highly flat and sloped inside walls of the 0.5 μ m-thick n-type GaN current block layers 315 cause current confinement as will be described later. A 0.3 μ m-thick p-type GaN contact layer 111 doped with Mg is provided over the 0.2 μ m-thick p-type GaN layer 214 as well as the highly flat and sloped inside walls and the top surfaces of the 0.5 μ m-thick n-type GaN current block layers 315. 15 A top surface of the 0.3 μ m-thick p-type GaN contact layer 111 is flat. The 0.3 μ m-thick p-type GaN contact layer 111 has the hexagonal crystal structure. A p-electrode 112 is provided which extends on the 0.3 μ m-thick p-type GaN contact layer 111. The p-electrode 112 comprises a nickel layer laminated on the top flat surface of the 0.3 μ m-thick p-type GaN contact layer 111 and a gold layer laminated on the nickel layer. An n-electrode 113 is provided on the recessed surface of the 3 μ m-thick n-type GaN contact layer 103. The n-electrode 113 20 comprises a titanium layer laminated on the 3 μ m-thick n-type GaN contact layer 103 and an aluminum layer laminated on the titanium layer.

25 As described above, since the 0.5 μ m-thick n-type GaN current block layers 315 have an opposite conductivity type to that of the 0.2 μ m-thick p-type GaN layer 214 and the 0.3 μ m-thick p-type GaN contact layer 111, then the 0.5 μ m-thick n-type GaN current block layers 315 are capable of blocking or guiding a current for current confinement. This current confinement allows a reduction in threshold current of the laser diode.

30 The above laser diode is formed as follows. The 300Å-thick undoped GaN buffer layer 102 is grown by a metal organic chemical vapor deposition method at a low temperature on the flat (0001)-face sapphire substrate 101 so that the 300Å-thick undoped GaN buffer layer 102 has a hexagonal crystal structure. The 3 μ m-thick n-type GaN contact layer 103 doped with Si is grown by a metal organic chemical vapor deposition

method on an entire surface of the 300Å-thick undoped GaN buffer layer 102 so that the 3 μm-thick n-type GaN contact layer 103 has a hexagonal crystal structure.

The 0.1 μm-thick n-type $\text{In}_{0.05}\text{Ga}_{0.95}\text{N}$ layer 104 doped with Si is grown by the metal organic chemical vapor deposition on the top surface of the ridged portion of the 3 μm-thick n-type GaN contact layer 103 so that the 0.1 μm-thick n-type $\text{In}_{0.05}\text{Ga}_{0.95}\text{N}$ layer 104 has a hexagonal crystal structure. The 0.4 μm-thick n-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 105 doped with Si is grown by the metal organic chemical vapor deposition on the 0.1 μm-thick n-type $\text{In}_{0.05}\text{Ga}_{0.95}\text{N}$ layer 104 so that the 0.4 μm-thick n-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 105 has the hexagonal crystal structure. The 0.1 μm-thick n-type GaN optical guide layer 106 doped with Si is grown by the metal organic chemical vapor deposition on the 0.4 μm-thick n-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 105 so that the 0.1 μm-thick n-type GaN optical guide layer 106 has the hexagonal crystal structure. The multiple quantum well active layer 107 is grown by the metal organic chemical vapor deposition on the 0.1 μm-thick n-type GaN optical guide layer 106, wherein the multiple quantum well active layer 107 comprises 7 periods of alternating 25Å-thick undoped $\text{In}_{0.2}\text{Ga}_{0.8}\text{N}$ quantum well layers and 50Å-thick undoped $\text{In}_{0.05}\text{Ga}_{0.95}\text{N}$ barrier layers. The 25Å-thick undoped $\text{In}_{0.2}\text{Ga}_{0.8}\text{N}$ quantum well layers and the 50Å-thick undoped $\text{In}_{0.05}\text{Ga}_{0.95}\text{N}$ barrier layers have the hexagonal crystal structure.

The 200Å-thick p-type $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$ layer 108 doped with Mg is grown by the metal organic chemical vapor deposition on the multiple quantum well active layer 107 so that the 200Å-thick p-type $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$ layer 108 has the hexagonal crystal structure. The 200Å-thick p-type $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$ layer 108 is capable of preventing dissociation of indium from the multiple quantum well active layer 107. The 0.1 μm-thick p-type GaN optical guide layer 109 doped with Mg is grown by the metal organic chemical vapor deposition on the 200Å-thick p-type $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$ layer 108 so that the 0.1 μm-thick p-type GaN optical guide layer 109 has the hexagonal crystal structure. The 0.4 μm-thick p-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 110 doped with Mg is grown by the metal organic chemical vapor deposition on the 0.1 μm-thick p-type GaN optical guide layer 109 so that the 0.4 μm-thick p-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 110 has the hexagonal crystal structure. The 0.2 μm-thick p-type GaN layer 214 is grown by the metal organic chemical vapor deposition on the 0.4 μm-thick p-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 110 so that the 0.2 μm-thick p-type GaN layer 214 has the hexagonal crystal structure. Further, 2000Å-thick silicon oxide stripe masks 215 are arranged on the 0.2 μm-thick p-type GaN layer 214 so that a longitudinal direction of the 2000Å-thick silicon oxide stripe masks 215 is parallel to the [11-20] direction of the hexagonal crystal structure. The 2000Å-thick silicon oxide stripe masks 215 defines a stripe-shaped opening and has a width of 5 μm. 0.5 μm-thick n-type GaN current block layers 315 doped with Si are selec-

tively grown by the metal organic chemical vapor deposition on the 0.2 μm-thick p-type GaN layer 214 so that the 0.5 μm-thick n-type GaN current block layers 315 also have the hexagonal crystal structure. The 0.5 μm-thick n-type GaN current block layers 315 are grown by a selective growth of a metal organic chemical vapor deposition method using dielectric stripe masks, for which reason the 0.5 μm-thick n-type GaN current block layers 315 have highly flat and sloped inside walls. It is important that the 0.5 μm-thick n-type GaN current block layers 315 having the hexagonal crystal structure are selectively grown by the metal organic chemical vapor deposition method using dielectric stripe masks on the 0.2 μm-thick p-type GaN layer 214 having the hexagonal crystal structure. This results in the formation of the highly flat and sloped inside walls of the 0.5 μm-thick n-type GaN current block layers 315. The highly flat and sloped inside walls of the 0.5 μm-thick n-type GaN current block layers 315 cause current confinement. A 0.3 μm-thick p-type GaN contact layer 111 doped with Mg is grown by the metal organic chemical vapor deposition method over the 0.2 μm-thick p-type GaN layer 214 as well as the highly flat and sloped inside walls and the top surfaces of the 0.5 μm-thick n-type GaN current block layers 315 so that a top surface of the 0.3 μm-thick p-type GaN contact layer 111 is flat and the 0.3 μm-thick p-type GaN contact layer 111 has the hexagonal crystal structure. A nickel layer is laminated on the top flat surface of the 0.3 μm-thick p-type GaN contact layer 111 and a gold layer is laminated on the nickel layer thereby forming the p-electrode 112. A titanium layer is laminated on the 3 μm-thick n-type GaN contact layer 103 and an aluminum layer is laminated on the titanium layer thereby forming the n-electrode 113.

Since the 0.5 μm-thick n-type GaN current block layers 315 have an opposite conductivity type to that of the 0.2 μm-thick p-type GaN layer 214 and the 0.3 μm-thick p-type GaN contact layer 111, then the 0.5 μm-thick n-type GaN current block layers 315 are capable of blocking or guiding a current for current confinement. This current confinement allows a reduction in threshold current of the laser diode.

Since, further, the p-electrode 112 has a large contact area with the 0.311 μm-thick p-type GaN contact layer 111, a contact resistance between the p-electrode 112 and the 0.3 μm-thick p-type GaN contact layer 111 is small.

Furthermore, the above current confinement structure can be formed without use of the dry etching process.

Moreover, the multiple quantum well active layer 107 is formed on the flat surface. This results in no possibility of compositional modification or no variation in composition over position of the active layer.

Since the gallium nitride based compound semiconductor layers having the hexagonal crystal structure are selectively formed on the (0001)-face of the gallium ni-

tride layer, then the gallium nitride based compound semiconductor layers are almost not grown in the [1-100] direction.

Namely, the 0.5 μ m-thick n-type GaN current block layers 315 having the hexagonal structure are selectively grown on the (0001)-face of the 0.2 μ m-thick p-type GaN layer 214 having the hexagonal crystal structure by use of the dielectric stripe masks arranged in a longitudinal direction along the [11-20] direction so that no extending portion over the dielectric stripe masks is formed.

In the above gallium nitride based compound semiconductor laser diode, an optical waveguide is formed in a direction along the [11-20] direction of the crystal structure. It is difficult to cleave the semiconductor wafer in the [11-20] direction. This means it difficult to form the reflective faces of resonator in the laser diode by the cleaving method. For this reason, it is necessary to form the reflective faces of resonator in the laser diode by other method such as dry etching.

Since the gallium nitride based compound semiconductor layers having the hexagonal crystal structure are selectively formed on the (0001)-face of the gallium nitride layer, then a growth rate of gallium nitride in the [11-20] direction is almost the same as that in the [0001] direction.

As a modification, the optical waveguide may be formed in a direction tilted from the [11-20] direction of the crystal structure by an angle in the range of ± 5 degrees. Even if the optical waveguide is formed in a direction tilted from the [11-20] direction of the crystal structure by an angle over the range of ± 5 degrees, then there is no problem unless the semiconductor layer is allowed to be selectively grown in the [11-20] direction. In the later case, however, it is necessary that the dielectric strip masks are almost the same in thickness as the current block layers.

Whereas in the above embodiment the semiconductor layers having the hexagonal crystal structure are grown on the (0001)-face of the sapphire substrate, it is also possible to grow the semiconductor layers having the hexagonal crystal structure on the (11-20)-face of the sapphire substrate.

Further, in place of the (0001)-face sapphire substrate and the (11-20)-face sapphire substrate, silicon oxide substrates with the (0001)-face or the (11-20)-face are available. Furthermore, $MgAl_2O_4$ substrates with the (0001)-face or the (11-20)-face are also available. Gallium nitride substrates with the (0001)-face or the (11-20)-face are still further available. The sapphire substrate, silicon oxide substrate, $MgAl_2O_4$ substrate, and gallium nitride substrate having other faces than the (0001)-face or the (11-20)-face are also available.

The above present invention can be applied not only to the gallium nitride based laser diode as illustrated in the drawings but also other gallium nitride based laser diodes which are different in thickness of layer, composition of layer, doping concentration of layer, material of

electrode, material of dielectric stripe masks, depth of dry etching, and width of stripe of the dielectric stripe masks.

Although in the above embodiment, the individual semiconductor layers have surfaces of the (0001)-face, the surfaces of the individual semiconductor layers may be tilted from the (0001)-face by an angle in the range of ± 5 degrees.

FIFTH EMBODIMENT:

A fifth embodiment according to the present invention will be described with reference to FIGS. 11 and 12. FIG. 11 is a fragmentary cross sectional elevation view illustrative of a novel gallium nitride based compound semiconductor laser having a current block layer structure for a current confinement in a fifth embodiment according to the present invention. FIG. 12 is a fragmentary cross sectional elevation view illustrative of a novel gallium nitride based compound semiconductor laser in a selective growth process by a metal organic chemical vapor deposition method involved in a fabrication method thereof.

The novel gallium nitride based compound semiconductor laser is formed on a (0001)-face sapphire substrate 101. All of compound semiconductor layers in the novel gallium nitride based compound semiconductor laser have hexagonal crystal structures. The structure of the novel gallium nitride based compound semiconductor laser is as follows. A 300Å-thick undoped GaN buffer layer 102 is provided on a (0001)-face sapphire substrate 101.

The 300Å-thick undoped GaN buffer layer 102 has a hexagonal crystal structure. A 3 μ m-thick n-type GaN contact layer 103 doped with Si is provided on an entire surface of the 300Å-thick undoped GaN buffer layer 102. The 3 μ m-thick n-type GaN contact layer 103 has a hexagonal crystal structure. The 3 μ m-thick n-type GaN contact layer 103 has a ridged portion and recess portions. A top surface of the ridged portion of the 3 μ m-thick n-type GaN contact layer 103 is a flat surface. Upper surfaces of the recess portions of the 3 μ m-thick n-type GaN contact layer 103 are also flat surfaces. A 0.1 μ m-thick n-type $In_{0.05}Ga_{0.95}N$ layer 104 doped with Si is provided on the top flat surface of the ridged portion of the 3 μ m-thick n-type GaN contact layer 103. The 0.1 μ m-thick n-type $In_{0.05}Ga_{0.95}N$ layer 104 is capable of preventing crack in the compound semiconductor. A 0.4 μ m-thick n-type $Al_{0.07}Ga_{0.93}N$ cladding layer 105 doped with Si is provided on the 0.1 μ m-thick n-type $In_{0.05}Ga_{0.95}N$ layer 104. The 0.4 μ m-thick n-type $Al_{0.07}Ga_{0.93}N$ cladding layer 105 has the hexagonal crystal structure. A 0.1 μ m-thick n-type GaN optical guide layer 106 doped with Si is provided on the 0.4 μ m-thick n-type $Al_{0.07}Ga_{0.93}N$ cladding layer 105. The 0.1 μ m-thick n-type GaN optical guide layer 106 has the hexagonal crystal structure. A multiple quantum well active layer 107 is provided on the 0.1 μ m-thick n-type GaN optical guide layer 106. The multiple quantum well

active layer 107 comprises 7 periods of alternating 25Å-thick undoped $\text{In}_{0.2}\text{Ga}_{0.8}\text{N}$ quantum well layers and 50Å-thick undoped $\text{In}_{0.05}\text{Ga}_{0.95}\text{N}$ barrier layers. The 25 Å-thick undoped $\text{In}_{0.2}\text{Ga}_{0.8}\text{N}$ quantum well layers have the hexagonal crystal structure. The 50Å-thick undoped $\text{In}_{0.05}\text{Ga}_{0.95}\text{N}$ barrier layers have the hexagonal crystal structure. A 200Å-thick p-type $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$ layer 108 doped with Mg is provided on the multiple quantum well active layer 107. The 200Å-thick p-type $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$ layer 108 has the hexagonal crystal structure. A 0.1 μm-thick p-type GaN optical guide layer 109 doped with Mg is provided on the 200Å-thick p-type $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$ layer 108. The 0.1 μm-thick p-type GaN optical guide layer 109 has the hexagonal crystal structure. A 0.4 μm-thick p-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 110 doped with Mg is provided on the 0.1 μm-thick p-type GaN optical guide layer 109. The 0.4 μm-thick p-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 110 has the hexagonal crystal structure. A 0.2 μm-thick p-type GaN layer 214 doped with Mg is provided on the 0.4 μm-thick p-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 110. The 0.2 μm-thick p-type GaN layer 214 has the hexagonal crystal structure. The above laminations of the 0.1 μm-thick n-type $\text{In}_{0.05}\text{Ga}_{0.95}\text{N}$ layer 104, the 0.4 μm-thick n-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 105, the 0.1 μm-thick n-type GaN optical guide layer 106, the multiple quantum well active layer 107, the 200Å-thick p-type $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$ layer 108, the 0.1 μm-thick p-type GaN optical guide layer 109, the 0.4 μm-thick p-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 110 and the 0.2 μm-thick p-type GaN layer 214 are in the form of a ridge. Further, GaN current block layer structures are provided on side walls of the ridge of the above laminations and over the 3 μm-thick n-type GaN contact layer 103. Each of the GaN current block layer structures comprise laminations of a 0.5 μm-thick n-type GaN current block layer 315 doped with Si, a 0.5 μm-thick p-type GaN current block layer 114 doped with Mg on the 0.5 μm-thick n-type GaN current block layers 315 and a 0.5 μm-thick n-type GaN current block layer 315 doped with Si on the 0.5 μm-thick p-type GaN current block layer 114. The 0.5 μm-thick n-type GaN current block layers 315 doped with Si are selectively provided on the side walls of the ridge of the above laminations of the layers and also over the 3 μm-thick n-type GaN contact layer 103. The 0.5 μm-thick n-type GaN current block layers 315 also have the hexagonal crystal structure. As will be described later, the 0.5 μm-thick n-type GaN current block layers 315 are grown by a selective growth of a metal organic chemical vapor deposition method using dielectric stripe masks arranged on a top of the ridge of the above laminations of the layers. It is important that the 0.5 μm-thick n-type GaN current block layers 315 having the hexagonal crystal structure are selectively grown by the metal organic chemical vapor deposition method using dielectric stripe masks on the side walls of the ridge of the above laminations of the layers having the hexagonal crystal structure and also over the 3 μm-thick n-type GaN contact layer 103 having the hexagonal

crystal structure. Subsequently, the 0.5 μm-thick p-type GaN current block layers 114 doped with Mg are also grown on the 0.5 μm-thick n-type GaN current block layers 315 by the selective growth of the metal organic chemical vapor deposition method using dielectric stripe masks arranged on a top of the ridge of the above laminations of the layers. It is also important that the 0.5 μm-thick p-type GaN current block layers 114 having the hexagonal crystal structure are selectively grown on the 0.5 μm-thick n-type GaN current block layers 315 having the hexagonal crystal structure by the metal organic chemical vapor deposition method using dielectric stripe masks. Then, the 0.5 μm-thick n-type GaN current block layers 315 are grown by the selective growth of the metal organic chemical vapor deposition method using dielectric stripe masks arranged on the top of the ridge of the above laminations of the layers. It is also important that the 0.5 μm-thick n-type GaN current block layers 315 having the hexagonal crystal structure are selectively grown on the 0.5 μm-thick p-type GaN current block layers 114 having the hexagonal crystal structure by the metal organic chemical vapor deposition method using dielectric stripe masks. Top surfaces of the upper 0.5 μm-thick n-type GaN current block layers 315 have the same level as a top surface of the 0.2 μm-thick p-type GaN layer 214 or the top of the ridge of the above laminations of layer. The current block layer structures of laminations of the 0.5 μm-thick n-type GaN current block layers 315, the 0.2 μm-thick p-type GaN layer 214 and the 0.5 μm-thick n-type GaN current block layers 315 cause current confinement as will be described later. A 0.2 μm-thick p-type GaN contact layer 111 doped with Mg is provided over the 0.2 μm-thick p-type GaN layer 214 as well as the top surfaces of the upper 0.5 μm-thick n-type GaN current block layers 315. A top surface of the 0.2 μm-thick p-type GaN contact layer 111 is flat. The 0.2 μm-thick p-type GaN contact layer 111 has the hexagonal crystal structure. A p-electrode 112 is provided which extends on the 0.2 μm-thick p-type GaN contact layer 111. The p-electrode 112 comprises a nickel layer laminated on the top flat surface of the 0.2 μm-thick p-type GaN contact layer 111 and a gold layer laminated on the nickel layer. An n-electrode 113 is provided on the recessed surface of the 3 μm-thick n-type GaN contact layer 103. The n-electrode 113 comprises a titanium layer laminated on the 3 μm-thick n-type GaN contact layer 103 and an aluminum layer laminated on the titanium layer.

As described above, since the 0.5 μm-thick n-type GaN current block layers 315 have an opposite conductivity type to that of the 0.2 μm-thick p-type GaN layer 214 and the 0.2 μm-thick p-type GaN contact layer 111, then the 0.5 μm-thick n-type GaN current block layers 315 are capable of blocking or guiding a current for current confinement. This current confinement allows a reduction in threshold current of the laser diode.

The above laser diode is formed as follows. The 300Å-thick undoped GaN buffer layer 102 is grown by

a metal organic chemical vapor deposition method at a low temperature on the flat (0001)-face sapphire substrate 101 so that the 300Å-thick undoped GaN buffer layer 102 has a hexagonal crystal structure. The 3 μm-thick n-type GaN contact layer 103 doped with Si is grown by a metal organic chemical vapor deposition method on an entire surface of the 300Å-thick undoped GaN buffer layer 102 so that the 3 μm-thick n-type GaN contact layer 103 has a hexagonal crystal structure. The 0.1 μm-thick n-type $In_{0.05}Ga_{0.95}N$ layer 104 doped with Si is grown by the metal organic chemical vapor deposition on the top surface of the ridged portion of the 3 μm-thick n-type GaN contact layer 103 so that the 0.1 μm-thick n-type $In_{0.05}Ga_{0.95}N$ layer 104 has a hexagonal crystal structure. The 0.4 μm-thick n-type $Al_{0.07}Ga_{0.93}N$ cladding layer 105 doped with Si is grown by the metal organic chemical vapor deposition on the 0.1 μm-thick n-type $In_{0.05}Ga_{0.95}N$ layer 104 so that the 0.4 μm-thick n-type $Al_{0.07}Ga_{0.93}N$ cladding layer 105 has the hexagonal crystal structure. The 0.1 μm-thick n-type GaN optical guide layer 106 doped with Si is grown by the metal organic chemical vapor deposition on the 0.4 μm-thick n-type $Al_{0.07}Ga_{0.93}N$ cladding layer 105 so that the 0.1 μm-thick n-type GaN optical guide layer 106 has the hexagonal crystal structure. The multiple quantum well active layer 107 is grown by the metal organic chemical vapor deposition on the 0.1 μm-thick n-type GaN optical guide layer 106, wherein the multiple quantum well active layer 107 comprises 7 periods of alternating 25Å-thick undoped $In_{0.2}Ga_{0.8}N$ quantum well layers and 50Å-thick undoped $In_{0.05}Ga_{0.95}N$ barrier layers. The 25Å-thick undoped $In_{0.2}Ga_{0.8}N$ quantum well layers and the 50Å-thick undoped $In_{0.05}Ga_{0.95}N$ barrier layers have the hexagonal crystal structure.

The 200Å-thick p-type $Al_{0.2}Ga_{0.8}N$ layer 108 doped with Mg is grown by the metal organic chemical vapor deposition on the multiple quantum well active layer 107 so that the 200Å-thick p-type $Al_{0.2}Ga_{0.8}N$ layer 108 has the hexagonal crystal structure. The 200Å-thick p-type $Al_{0.2}Ga_{0.8}N$ layer 109 is capable of preventing dissociation of indium from the multiple quantum well active layer 107. The 0.1 μm-thick p-type GaN optical guide layer 109 doped with Mg is grown by the metal organic chemical vapor deposition on the 200Å-thick p-type $Al_{0.2}Ga_{0.8}N$ layer 108 so that the 0.1 μm-thick p-type GaN optical guide layer 109 has the hexagonal crystal structure. The 0.4 μm-thick p-type $Al_{0.07}Ga_{0.93}N$ cladding layer 110 doped with Mg is grown by the metal organic chemical vapor deposition on the 0.1 μm-thick p-type GaN optical guide layer 109 so that the 0.4 μm-thick p-type $Al_{0.07}Ga_{0.93}N$ cladding layer 110 has the hexagonal crystal structure. The 0.2 μm-thick p-type GaN layer 214 is grown by the metal organic chemical vapor deposition on the 0.4 μm-thick p-type $Al_{0.07}Ga_{0.93}N$ cladding layer 110 so that the 0.2 μm-thick p-type GaN layer 214 has the hexagonal crystal structure. Further, 2000Å-thick silicon oxide stripe masks 215 are arranged on the 0.2 μm-thick p-type GaN layer 214

so that a longitudinal direction of the 2000Å-thick silicon oxide stripe masks 215 is parallel to the [11-20] direction of the hexagonal crystal structure. The 2000Å-thick silicon oxide stripe masks 215 defines a stripe-shaped opening and has a width of 1 μm. A reactive ion etching is carried out to selectively remove the above laminations of the 0.1 μm-thick n-type $In_{0.05}Ga_{0.95}N$ layer 104, the 0.4 μm-thick n-type $Al_{0.07}Ga_{0.93}N$ cladding layer 105, the 0.1 μm-thick n-type GaN optical guide layer 106, the multiple quantum well active layer 107, the 200Å-thick p-type $Al_{0.2}Ga_{0.8}N$ layer 108, the 0.1 μm-thick p-type GaN optical guide layer 109, the 0.4 μm-thick p-type $Al_{0.07}Ga_{0.93}N$ cladding layer 110 and the 0.2 μm-thick p-type GaN layer 214 and further the 3 μm-thick n-type GaN contact layer 103. As a result, the ridge is formed which comprises the above semiconductor layers having the hexagonal crystal structure. Further, GaN current block layer structures are formed on side walls of the ridge of the above laminations and over the 3 μm-thick n-type GaN contact layer 103. The 0.5 μm-thick n-type GaN current block layers 315 doped with Si are selectively grown on the side walls of the ridge of the above laminations of the layers and also over the 3 μm-thick n-type GaN contact layer 103 by the metal organic chemical vapor deposition method using the above 2000Å-thick silicon oxide stripe masks 215 so that the 0.5 μm-thick n-type GaN current block layers 315 also have the hexagonal crystal structure. It is important that the 0.5 μm-thick n-type GaN current block layers 315 having the hexagonal crystal structure are selectively grown by the metal organic chemical vapor deposition method using dielectric stripe masks on the side walls of the ridge of the above laminations of the layers having the hexagonal crystal structure and also over the 3 μm-thick n-type GaN contact layer 103 having the hexagonal crystal structure. Subsequently, the 0.5 μm-thick p-type GaN current block layers 114 doped with Mg are also grown on the 0.5 μm-thick n-type GaN current block layers 315 by the selective growth of the metal organic chemical vapor deposition method using dielectric stripe masks arranged on the top of the ridge of the above laminations of the layers. It is also important that the 0.5 μm-thick p-type GaN current block layers 114 having the hexagonal crystal structure are selectively grown on the 0.5 μm-thick n-type GaN current block layers 315 having the hexagonal crystal structure by the metal organic chemical vapor deposition method using dielectric stripe masks. Then, the 0.5 μm-thick n-type GaN current block layers 315 are grown by the selective growth of the metal organic chemical vapor deposition method using dielectric stripe masks arranged on the top of the ridge of the above laminations of the layers. It is also important that the 0.5 μm-thick n-type GaN current block layers 315 having the hexagonal crystal structure are selectively grown on the 0.5 μm-thick p-type GaN current block layers 114 having the hexagonal crystal structure by the metal organic chemical vapor deposition method using dielectric stripe

masks. Top surfaces of the upper $0.5 \mu m$ -thick n-type GaN current block layers 315 have the same level as a top surface of the $0.2 \mu m$ -thick p-type GaN layer 214 or the top of the ridge of the above laminations of layer. The current block layer structures of laminations of the $0.5 \mu m$ -thick n-type GaN current block layers 315, the $0.2 \mu m$ -thick p-type GaN layer 214 and the $0.5 \mu m$ -thick n-type GaN current block layers 315 cause current confinement. The used 2000\AA -thick silicon oxide stripe masks 215 are removed. A $0.3 \mu m$ -thick p-type GaN contact layer 111 doped with Mg is grown by the metal organic chemical vapor deposition method over the $0.2 \mu m$ -thick p-type GaN layer 214 as well as the top surfaces of the upper $0.5 \mu m$ -thick n-type GaN current block layers 315 so that a top surface of the $0.3 \mu m$ -thick p-type GaN contact layer 111 is flat and the $0.3 \mu m$ -thick p-type GaN contact layer 111 has the hexagonal crystal structure. A p-electrode 112 is provided which extends on the $0.3 \mu m$ -thick p-type GaN contact layer 111. The p-electrode 112 comprises a nickel layer laminated on the top flat surface of the $0.3 \mu m$ -thick p-type GaN contact layer 111 and a gold layer laminated on the nickel layer. An n-electrode 113 is provided on the recessed surface of the $3 \mu m$ -thick n-type GaN contact layer 103. The n-electrode 113 comprises a titanium layer laminated on the $3 \mu m$ -thick n-type GaN contact layer 103 and an aluminum layer laminated on the titanium layer.

Since the $0.5 \mu m$ -thick n-type GaN current block layers 315 have an opposite conductivity type to that of the $0.2 \mu m$ -thick p-type GaN layer 214 and the $0.2 \mu m$ -thick p-type GaN contact layer 111, then the $0.5 \mu m$ -thick n-type GaN current block layers 315 are capable of blocking or guiding a current for current confinement. This current confinement allows a reduction in threshold current of the laser diode.

Since, further, the p-electrode 112 has a large contact area with the $0.3 \mu m$ -thick p-type GaN contact layer 111, a contact resistance between the p-electrode 112 and the $0.3 \mu m$ -thick p-type GaN contact layer 111 is small.

Furthermore, the above current confinement structure can be formed without use of the dry etching process.

Moreover, the multiple quantum well active layer 107 is formed on the flat surface. This results in no possibility of compositional modification or no variation in composition over position of the active layer.

Namely, the $0.5 \mu m$ -thick n-type GaN current block layers 315 having the hexagonal structure are selectively grown on the (0001)-face of the $0.2 \mu m$ -thick p-type GaN layer 214 having the hexagonal crystal structure and the $3 \mu m$ -thick n-type GaN contact layer 103 having the hexagonal crystal structure by use of the dielectric stripe masks arranged in a longitudinal direction along the [1-100] direction so that an optical waveguide is formed in a direction along the [1-100] direction of the crystal structure. It is, therefore, possible to cleave the

semiconductor wafer in the [1-100] direction. This means it possible to form the reflective faces of resonator in the laser diode by the cleaving method.

As a modification, the optical waveguide may be formed in a direction tilted from the [1-100] direction of the crystal structure by an angle in the range of ± 5 degrees. Even if the optical waveguide is formed in a direction tilted from the [1-100] direction of the crystal structure by an angle over the range of ± 5 degrees, then it is difficult to cleave the semiconductor wafer, for which reason the reflective faces of resonator in the laser diode are formed by other methods such as dry etching than the cleaving method.

Whereas in the above embodiment the semiconductor layers having the hexagonal crystal structure are grown on the (0001)-face of the sapphire substrate, it is also possible to grow the semiconductor layers having the hexagonal crystal structure on the (11-20)-face of the sapphire substrate.

Further, in place of the (0001)-face sapphire substrate and the (11-20)-face sapphire substrate, silicon oxide substrates with the (0001)-face or the (11-20)-face are available. Furthermore, MgAl_2O_4 substrates with the (0001)-face or the (11-20)-face are also available. Gallium nitride substrates with the (0001)-face or the (11-20)-face are still further available. The sapphire substrate, silicon oxide substrate, MgAl_2O_4 substrate, and gallium nitride substrate having other faces than the (0001)-face or the (11-20)-face are also available.

The above present invention can be applied not only to the gallium nitride based laser diode as illustrated in the drawings but also other gallium nitride based laser diodes which are different in thickness of layer, composition of layer, doping concentration of layer, material of electrode, material of dielectric stripe masks, depth of dry etching, and width of stripe of the dielectric stripe masks.

Although in the above embodiment, the individual semiconductor layers have surfaces of the (0001)-face, the surfaces of the individual semiconductor layers may be tilted from the (0001)-face by an angle in the range of ± 5 degrees.

SIXTH EMBODIMENT:

A sixth embodiment according to the present invention will be described with reference to FIGS. 13 and 14. FIG. 13 is a fragmentary cross sectional elevation view illustrative of a novel gallium nitride based compound semiconductor laser having a current block layer structure for a current confinement in a sixth embodiment according to the present invention. FIG. 14 is a fragmentary cross sectional elevation view illustrative of a novel gallium nitride based compound semiconductor laser in a selective growth process by a metal organic chemical vapor deposition method involved in a fabrication method thereof.

The novel gallium nitride based compound semiconductor laser is formed on a (0001)-face sapphire

substrate 101. All of compound semiconductor layers in the novel gallium nitride based compound semiconductor laser have hexagonal crystal structures. The structure of the novel gallium nitride based compound semiconductor laser is as follows. A 300Å-thick undoped GaN buffer layer 102 is provided on a (0001)-face sapphire substrate 101. The 300Å-thick undoped GaN buffer layer 102 has a hexagonal crystal structure. A 3 μ m-thick n-type GaN contact layer 103 doped with Si is provided on an entire surface of the 300Å-thick undoped GaN buffer layer 102. The 3 μ m-thick n-type GaN contact layer 103 has a hexagonal crystal structure. The 3 μ m-thick n-type GaN contact layer 103 has a ridged portion and recess portions. A top surface of the ridged portion of the 3 μ m-thick n-type GaN contact layer 103 is a flat surface. Upper surfaces of the recess portions of the 3 μ m-thick n-type GaN contact layer 103 are also flat surfaces. A 0.1 μ m-thick n-type $In_{0.05}Ga_{0.95}N$ layer 104 doped with Si is provided on the top flat surface of the ridged portion of the 3 μ m-thick n-type GaN contact layer 103. The 0.1 μ m-thick n-type $In_{0.05}Ga_{0.95}N$ layer 104 is capable of preventing crack in the compound semiconductor. A 0.4 μ m-thick n-type $Al_{0.07}Ga_{0.93}N$ cladding layer 105 doped with Si is provided on the 0.1 μ m-thick n-type $In_{0.05}Ga_{0.95}N$ layer 104. The 0.4 μ m-thick n-type $Al_{0.07}Ga_{0.93}N$ cladding layer 105 has the hexagonal crystal structure. A 0.1 μ m-thick n-type GaN optical guide layer 106 doped with Si is provided on the 0.4 μ m-thick n-type $Al_{0.07}Ga_{0.93}N$ cladding layer 105. The 0.1 μ m-thick n-type GaN optical guide layer 106 has the hexagonal crystal structure. A multiple quantum well active layer 107 is provided on the 0.1 μ m-thick n-type GaN optical guide layer 106. The multiple quantum well active layer 107 comprises 7 periods of alternating 25Å-thick undoped $In_{0.2}Ga_{0.8}N$ quantum well layers and 50Å-thick undoped $In_{0.05}Ga_{0.95}N$ barrier layers. The 25 Å-thick undoped $In_{0.2}Ga_{0.8}N$ quantum well layers have the hexagonal crystal structure. The 50Å-thick undoped $In_{0.05}Ga_{0.95}N$ barrier layers have the hexagonal crystal structure. A 200Å-thick p-type $Al_{0.2}Ga_{0.8}N$ layer 108 doped with Mg is provided on the multiple quantum well active layer 107. The 200Å-thick p-type $Al_{0.2}Ga_{0.8}N$ layer 108 has the hexagonal crystal structure. A 0.1 μ m-thick p-type GaN optical guide layer 109 doped with Mg is provided on the 200Å-thick p-type $Al_{0.2}Ga_{0.8}N$ layer 108. The 0.1 μ m-thick p-type GaN optical guide layer 109 has the hexagonal crystal structure. A 0.4 μ m-thick p-type $Al_{0.07}Ga_{0.93}N$ cladding layer 110 doped with Mg is provided on the 0.1 μ m-thick p-type GaN optical guide layer 109. The 0.4 μ m-thick p-type $Al_{0.07}Ga_{0.93}N$ cladding layer 110 has the hexagonal crystal structure. A 0.2 μ m-thick p-type GaN layer 214 doped with Mg is provided on the 0.4 μ m-thick p-type $Al_{0.07}Ga_{0.93}N$ cladding layer 110. The 0.2 μ m-thick p-type GaN layer 214 has the hexagonal crystal structure. The 0.2 μ m-thick p-type GaN layer 214 has a ridged portion and flat base portions. Further, 0.5 μ m-thick n-type GaN current block layers 315 doped with Si are selectively provided on the

side walls of the ridged portion of the 0.2 μ m-thick p-type GaN layer and also over the flat base portions of the 0.2 μ m-thick p-type GaN layer 214. The 0.5 μ m-thick n-type GaN current block layers 315 also have the hexagonal crystal structure. As will be described later, the 0.5 μ m-thick n-type GaN current block layers 315 are grown by a selective growth of a metal organic chemical vapor deposition method using dielectric stripe masks arranged on a top of the ridged portion of the 0.2 μ m-thick p-type GaN layer 214. It is important that the 0.5 μ m-thick n-type GaN current block layers 315 having the hexagonal crystal structure are selectively grown by the metal organic chemical vapor deposition method using dielectric stripe masks on the side walls of the 10 ridged portion of the 0.2 μ m-thick p-type GaN layer 214 and also over the flat base portions of the 0.2 μ m-thick p-type GaN layer 214 having the hexagonal crystal structure. Top surfaces of the 0.5 μ m-thick n-type GaN current block layers 315 have the same level as a top 15 surface of the 0.2 μ m-thick p-type GaN layer 214. The current block layer structure of the 0.5 μ m-thick n-type GaN current block layers 315 cause current confinement as will be described later. A 0.3 μ m-thick p-type GaN contact layer 111 doped with Mg is provided over 20 the 0.2 μ m-thick p-type GaN layer 214 as well as the top surfaces of the upper 0.5 μ m-thick n-type GaN current block layers 315. A top surface of the 0.3 μ m-thick p-type GaN contact layer 111 is flat. The 0.3 μ m-thick p-type GaN contact layer 111 has the hexagonal crystal structure. A p-electrode 112 is provided which extends 25 on the 0.3 μ m-thick p-type GaN contact layer 111. The p-electrode 112 comprises a nickel layer laminated on the top flat surface of the 0.3 μ m-thick p-type GaN contact layer 111 and a gold layer laminated on the nickel layer. An n-electrode 113 is provided on the recessed 30 surface of the 3 μ m-thick n-type GaN contact layer 103. The n-electrode 113 comprises a titanium layer laminated on the 3 μ m-thick n-type GaN contact layer 103 and an aluminum layer laminated on the titanium layer. 35 As described above, since the 0.5 μ m-thick n-type GaN current block layers 315 have an opposite conductivity type to that of the 0.2 μ m-thick p-type GaN layer 214 and the 0.3 μ m-thick p-type GaN contact layer 111, then the 0.5 μ m-thick n-type GaN current block layers 40 315 are capable of blocking or guiding a current for current confinement. This current confinement allows a reduction in threshold current of the laser diode. 45 The above laser diode is formed as follows. The 300Å-thick undoped GaN buffer layer 102 is grown by a metal organic chemical vapor deposition method at a low temperature on the flat (0001)-face sapphire substrate 101 so that the 300Å-thick undoped GaN buffer layer 102 has a hexagonal crystal structure. The 3 μ m-thick n-type GaN contact layer 103 doped with Si is 50 provided by a metal organic chemical vapor deposition method on an entire surface of the 300Å-thick undoped GaN buffer layer 102 so that the 3 μ m-thick n-type GaN contact layer 103 has a hexagonal crystal structure. The

0.1 μ m-thick n-type $\text{In}_{0.05}\text{Ga}_{0.95}\text{N}$ layer 104 doped with Si is grown by the metal organic chemical vapor deposition on the top surface of the ridged portion of the 3 μ m-thick n-type GaN contact layer 103 so that the 0.1 μ m-thick n-type $\text{In}_{0.05}\text{Ga}_{0.95}\text{N}$ layer 104 has a hexagonal crystal structure. The 0.4 μ m-thick n-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 105 doped with Si is grown by the metal organic chemical vapor deposition on the 0.1 μ m-thick n-type $\text{In}_{0.05}\text{Ga}_{0.95}\text{N}$ layer 104 so that the 0.4 μ m-thick n-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 105 has the hexagonal crystal structure. The 0.1 μ m-thick n-type GaN optical guide layer 106 doped with Si is grown by the metal organic chemical vapor deposition on the 0.4 μ m-thick n-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 105 so that the 0.1 μ m-thick n-type GaN optical guide layer 106 has the hexagonal crystal structure. The multiple quantum well active layer 107 is grown by the metal organic chemical vapor deposition on the 0.1 μ m-thick n-type GaN optical guide layer 106, wherein the multiple quantum well active layer 107 comprises 7 periods of alternating 25Å-thick undoped $\text{In}_{0.2}\text{Ga}_{0.8}\text{N}$ quantum well layers and 50Å-thick undoped $\text{In}_{0.05}\text{Ga}_{0.95}\text{N}$ barrier layers. The 25Å-thick undoped $\text{In}_{0.2}\text{Ga}_{0.8}\text{N}$ quantum well layers and the 50Å-thick undoped $\text{In}_{0.05}\text{Ga}_{0.95}\text{N}$ barrier layers have the hexagonal crystal structure.

The 200Å-thick p-type $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$ layer 108 doped with Mg is grown by the metal organic chemical vapor deposition on the multiple quantum well active layer 107 so that the 200Å-thick p-type $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$ layer 108 has the hexagonal crystal structure. The 200Å-thick p-type $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$ layer 108 is capable of preventing dissociation of indium from the multiple quantum well active layer 107. The 0.1 μ m-thick p-type GaN optical guide layer 109 doped with Mg is grown by the metal organic chemical vapor deposition on the 200Å-thick p-type $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$ layer 108 so that the 0.1 μ m-thick p-type GaN optical guide layer 109 has the hexagonal crystal structure. The 0.4 μ m-thick p-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 110 doped with Mg is grown by the metal organic chemical vapor deposition on the 0.1 μ m-thick p-type GaN optical guide layer 109 so that the 0.4 μ m-thick p-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 110 has the hexagonal crystal structure. The 0.2 μ m-thick p-type GaN layer 214 is grown by the metal organic chemical vapor deposition on the 0.4 μ m-thick p-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer 110 so that the 0.2 μ m-thick p-type GaN layer 214 has the hexagonal crystal structure. Further, 2000Å-thick silicon oxide stripe masks 215 are arranged on the 0.2 μ m-thick p-type GaN layer 214 so that a longitudinal direction of the 2000Å-thick silicon oxide stripe masks 215 is parallel to the [11-20] direction of the hexagonal crystal structure. The 2000Å-thick silicon oxide stripe masks 215 defines a stripe-shaped opening and has a width of 1 μ m. A reactive ion etching is carried out to selectively remove parts of the 0.2 μ m-thick p-type GaN layer 214. As a result, the ridge portion is formed. Further, 0.5 μ m-thick n-type GaN current block layers 315 doped with Si are selectively grown on

the side walls of the ridged portion of the 0.2 μ m-thick p-type GaN layer 214 and also over the flat base portions of the 0.2 μ m-thick p-type GaN layer 214 by the metal organic chemical vapor deposition method using the 2000Å-thick silicon oxide stripe masks 215 so that the 0.5 μ m-thick n-type GaN current block layers 315 also have the hexagonal crystal structure. The 0.5 μ m-thick n-type GaN current block layers 315 are grown by a selective growth of a metal organic chemical vapor deposition method using dielectric stripe masks arranged on a top of the ridged portion of the 0.2 μ m-thick p-type GaN layer 214. It is important that the 0.5 μ m-thick n-type GaN current block layers 315 having the hexagonal crystal structure are selectively grown by the metal organic chemical vapor deposition method using dielectric stripe masks on the side walls of the ridged portion of the 0.2 μ m-thick p-type GaN layer 214 and also over the flat base portions of the 0.2 μ m-thick p-type GaN layer 214 having the hexagonal crystal structure. Top surfaces of the 0.5 μ m-thick n-type GaN current block layers 315 have the same level as a top surface of the 0.2 μ m-thick p-type GaN layer 214. The current block layer structure of the 0.5 μ m-thick n-type GaN current block layers 315 cause current confinement. The used 2000Å-thick silicon oxide stripe masks 215 are removed. A 0.3 μ m-thick p-type GaN contact layer 111 doped with Mg is provided over the 0.2 μ m-thick p-type GaN layer 214 as well as the top surfaces of the upper 0.5 μ m-thick n-type GaN current block layers 315. A top surface of the 0.3 μ m-thick p-type GaN contact layer 111 is flat. The 0.3 μ m-thick p-type GaN contact layer 111 has the hexagonal crystal structure. A p-electrode 112 is formed which extends on the 0.3 μ m-thick p-type GaN contact layer 111. The p-electrode 112 comprises a nickel layer laminated on the top flat surface of the 0.3 μ m-thick p-type GaN contact layer 111 and a gold layer laminated on the nickel layer. An n-electrode 113 is formed on the recessed surface of the 3 μ m-thick n-type GaN contact layer 103. The n-electrode 113 comprises a titanium layer laminated on the 3 μ m-thick n-type GaN contact layer 103 and an aluminum layer laminated on the titanium layer.

Since the 0.5 μ m-thick n-type GaN current block layers 315 have an opposite conductivity type to that of the 0.2 μ m-thick p-type GaN layer 214 and the 0.2 μ m-thick p-type GaN contact layer 111, then the 0.5 μ m-thick n-type GaN current block layers 315 are capable of blocking or guiding a current for current confinement. This current confinement allows a reduction in threshold current of the laser diode.

Since, further, the p-electrode 112 has a large contact area with the 0.3 μ m-thick p-type GaN contact layer 111, a contact resistance between the p-electrode 112 and the 0.3 μ m-thick p-type GaN contact layer 111 is small.

Furthermore, the above current confinement structure can be formed without use of the dry etching process to the active layer.

Moreover, the multiple quantum well active layer 107 is formed on the flat surface. This results in no possibility of compositional modification or no variation in composition over position of the active layer.

Namely, the $0.5 \mu\text{m}$ -thick n-type GaN current block layers 315 having the hexagonal structure are selectively grown on the (0001)-face of the $0.2 \mu\text{m}$ -thick p-type GaN layer 214 having the hexagonal crystal structure and the $3 \mu\text{m}$ -thick n-type GaN contact layer 103 having the hexagonal crystal structure by use of the dielectric stripe masks arranged in a longitudinal direction along the [1-100] direction so that an optical waveguide is formed in a direction along the [1-100] direction of the crystal structure. It is, therefore, possible to cleave the semiconductor wafer in the [1-100] direction. This means it possible to form the reflective faces of resonator in the laser diode by the cleaving method.

As a modification, the optical waveguide may be formed in a direction tilted from the [1-100] direction of the crystal structure by an angle in the range of ± 5 degrees. Even if the optical waveguide is formed in a direction tilted from the [1-100] direction of the crystal structure by an angle over the range of ± 5 degrees, then it is difficult to cleave the semiconductor wafer, for which reason the reflective faces of resonator in the laser diode are formed by other methods such as dry etching than the cleaving method.

Whereas in the above embodiment the semiconductor layers having the hexagonal crystal structure are grown on the (0001)-face of the sapphire substrate, it is also possible to grow the semiconductor layers having the hexagonal crystal structure on the (11-20)-face of the sapphire substrate.

Further, in place of the (0001)-face sapphire substrate and the (11-20)-face sapphire substrate, silicon oxide substrates with the (0001)-face or the (11-20)-face are available. Furthermore, MgAl_2O_4 substrates with the (0001)-face or the (11-20)-face are also available. Gallium nitride substrates with the (0001)-face or the (11-20)-face are still further available. The sapphire substrate, silicon oxide substrate, MgAl_2O_4 substrate, and gallium nitride substrate having other faces than the (0001)-face or the (11-20)-face are also available.

The above present invention can be applied not only to the gallium nitride based laser diode as illustrated in the drawings but also other gallium nitride based laser diodes which are different in thickness of layer, composition of layer, doping concentration of layer, material of electrode, material of dielectric stripe masks, depth of dry etching, and width of stripe of the dielectric stripe masks.

Although in the above embodiment, the individual semiconductor layers have surfaces of the (0001)-face, the surfaces of the individual semiconductor layers may be tilted from the (0001)-face by an angle in the range of ± 5 degrees.

Whereas modifications of the present invention will be apparent to a person having ordinary skill in the art, to which the invention pertains, it is to be understood

that embodiments as shown and described by way of illustrations are by no means intended to be considered in a limiting sense. Accordingly, it is to be intended to cover by claims all modifications which fall within the spirit and scope of the present invention.

Claims

10. 1. A current block layer structure in a semiconductor device, said structure comprising at least a current block layer of a first compound semiconductor having a hexagonal crystal structure, said current block layer being selectively grown on at least a surface of a compound semiconductor region of a second compound semiconductor having said hexagonal crystal structure by use of dielectric stripe masks defining at least a stripe-shaped opening.
15. 2. The current block layer structure as claimed in claim 1, characterized in that said hexagonal crystal structure has a face tilted from a (0001)-face by an angle in the range of 0 degree to 10 degrees, and characterized in that said stripe-shaped opening of said dielectric stripe masks have a longitudinal direction having an included angle to a [11-20] direction in the range of -5 degrees to ± 5 degrees.
20. 3. The current block layer structure as claimed in claim 2, characterized in that said face of said hexagonal crystal structure is said (0001)-face.
25. 4. The current block layer structure as claimed in claim 2, characterized in that said longitudinal direction of said stripe-shaped opening of said dielectric stripe masks is parallel to said [11-20] direction.
30. 5. The current block layer structure as claimed in claim 1, characterized in that said hexagonal crystal structure has a face tilted from a (0001)-face by an angle in the range of 0 degree to 10 degrees, and characterized in that said stripe-shaped opening of said dielectric stripe masks have a longitudinal direction having an included angle to a [1-100] direction in the range of -5 degrees to ± 5 degrees.
35. 6. The current block layer structure as claimed in claim 5, characterized in that said face of said hexagonal crystal structure is said (0001)-face.
40. 7. The current block layer structure as claimed in claim 5, characterized in that said longitudinal direction of said stripe-shaped opening of said dielectric stripe masks is parallel to said [1-100] direction.
45. 8. The current block layer structure as claimed in claim 1, characterized in that said first compound semiconductor is of an opposite conductivity type

to that of said second compound semiconductor.

9. The current block layer structure as claimed in claim 8, characterized in that said first and second compound semiconductors are gallium nitride based semiconductors.

10. The current block layer structure as claimed in claim 9, characterized in that said first compound semiconductor is one selected from the group consisting of GaN, AlGaN, InGaN and InAlGaN.

11. The current block layer structure as claimed in claim 9, characterized in that said second compound semiconductor is one selected from the group consisting of GaN, AlGaN, InGaN and InAlGaN.

12. The current block layer structure as claimed in claim 8, characterized in that said first and second compound semiconductors are boron nitride based semiconductors.

13. The current block layer structure as claimed in claim 1, characterized in that said first compound semiconductor has a highly resistive compound semiconductor.

14. The current block layer structure as claimed in claim 13, characterized in that said highly resistive compound semiconductor is an undoped semiconductor.

15. The current block layer structure as claimed in claim 14, characterized in that said first and second compound semiconductors are gallium nitride based semiconductors.

16. The current block layer structure as claimed in claim 15, characterized in that said first compound semiconductor is one selected from the group consisting of GaN, AlGaN, InGaN and InAlGaN.

17. The current block layer structure as claimed in claim 15, characterized in that said second compound semiconductor is one selected from the group consisting of GaN, AlGaN, InGaN and InAlGaN.

18. The current block layer structure as claimed in claim 13, characterized in that said first and second compound semiconductors are boron nitride based semiconductors.

19. The current block layer structure as claimed in claim 1, characterized in that said compound semiconductor region comprises a compound semiconductor base layer having a flat top surface, and

5 characterized in that said current block layer is selectively grown on said flat top surface of said compound semiconductor base layer by use of said dielectric stripe masks provided on said flat top surface of said compound semiconductor base layer.

10 20. The current block layer structure as claimed in claim 19, further comprising an additional compound semiconductor layer of the same conductivity type as said compound semiconductor base layer and said additional compound semiconductor layer extending on both side walls and a top surface of said current block layer and also extending over said compound semiconductor base layer under said stripe-shaped opening.

15 21. The current block layer structure as claimed in claim 19, further comprising laminations of a plurality of additional compound semiconductor layers of the same conductivity type as said compound semiconductor base layer and said laminations of said plurality of additional compound semiconductor layers extending on both side walls and a top surface of said current block layer and also extending over said compound semiconductor base layer under said stripe-shaped opening.

20 22. The current block layer structure as claimed in claim 19, characterized in that a side wall of said current block layer is a vertical side wall.

25 23. The current block layer structure as claimed in claim 19, characterized in that a side wall of said current block layer is a sloped side wall.

30 24. The current block layer structure as claimed in claim 1, characterized in that said compound semiconductor region includes at least a flat base portion and at least a ridged portion, and characterized in that said current block layer is selectively grown both on said flat base portion and on side walls of said ridged portion by use of said dielectric stripe masks provided on a top portion of said ridged portion.

35 25. The current block layer structure as claimed in claim 24, characterized in that said current block layer comprises a single layer having a top surface which is substantially the same level as said top portion of said ridged portion.

40 26. The current block layer structure as claimed in claim 24, characterized in that said current block layer comprises laminations of a plurality of different layers and said laminations have a top surface which is substantially the same level as said top portion of said ridged portion.

27. The current block layer structure as claimed in claim 26, characterized in that said laminations comprise a first layer having an opposite conductivity type to said compound semiconductor region, a second layer being laminated on said first layer and having the same conductivity type as said compound semiconductor region, and a third layer being laminated on said second layer and having said opposite conductivity type to said compound semiconductor region.

28. The current block layer structure as claimed in claim 24, characterized in that said ridged portion includes laminations of a plurality of different compound semiconductor layers.

29. The current block layer structure as claimed in claim 24, characterized in that said ridged portion and said flat base portion comprises a single compound semiconductor layer having a ridged portion and etched portions.

30. The current block layer structure as claimed in claim 1, characterized in that said current block layer is selectively grown by a metal organic chemical vapor deposition method.

31. A gallium nitride based compound semiconductor laser having a current block layer structure which comprises :

current block layers of a first compound semiconductor having a hexagonal crystal structure, said current block layers being selectively grown on a flat top surface of a compound semiconductor base layer of a second compound semiconductor having said hexagonal crystal structure by use of dielectric stripe masks defining at least a stripe-shaped opening and being provided on said flat top surface of said compound semiconductor base layer; and at least an additional compound semiconductor layer of the same conductivity type as said compound semiconductor base layer and said additional compound semiconductor layer extending on both side walls and top surfaces of said current block layers and also extending over said compound semiconductor base layer under said stripe-shaped opening.

32. The gallium nitride based compound semiconductor laser as claimed in claim 31, characterized in that said hexagonal crystal structure has a face tilted from a (0001)-face by an angle in the range of 0 degree to 10 degrees, and characterized in that said stripe-shaped opening of said dielectric stripe masks have a longitudinal direction having an included angle to a [11-20] direction in the range of -5

degrees to ± 5 degrees.

33. The gallium nitride based compound semiconductor laser as claimed in claim 32, characterized in that said face of said hexagonal crystal structure is said (0001)-face.

34. The gallium nitride based compound semiconductor laser as claimed in claim 32, characterized in that said longitudinal direction of said stripe-shaped opening of said dielectric stripe masks is parallel to said [11-20] direction.

35. The gallium nitride based compound semiconductor laser as claimed in claim 31, characterized in that said hexagonal crystal structure has a face tilted from a (0001)-face by an angle in the range of 0 degree to 10 degrees, and characterized in that said stripe-shaped opening of said dielectric stripe masks have a longitudinal direction having an included angle to a [1-100] direction in the range of -5 degrees to ± 5 degrees.

36. The gallium nitride based compound semiconductor laser as claimed in claim 35, characterized in that said face of said hexagonal crystal structure is said (0001)-face.

37. The gallium nitride based compound semiconductor laser as claimed in claim 35, characterized in that said longitudinal direction of said stripe-shaped opening of said dielectric stripe masks is parallel to said [1-100] direction.

38. The gallium nitride based compound semiconductor laser as claimed in claim 31, characterized in that said first compound semiconductor is of an opposite conductivity type to that of said second compound semiconductor.

39. The gallium nitride based compound semiconductor laser as claimed in claim 38, characterized in that said first and second compound semiconductors are gallium nitride based semiconductors.

40. The gallium nitride based compound semiconductor laser as claimed in claim 39, characterized in that said first and second compound semiconductor are ones selected from the group consisting of GaN, AlGaN, InGaN and InAlGaN.

41. The gallium nitride based compound semiconductor laser as claimed in claim 38, characterized in that said first and second compound semiconductors are boron nitride based semiconductors.

42. The gallium nitride based compound semiconductor laser as claimed in claim 31, characterized

in that said first compound semiconductor has a highly resistive compound semiconductor.

43. The gallium nitride based compound semiconductor laser as claimed in claim 42, characterized in that said highly resistive compound semiconductor is an undoped semiconductor.

44. The gallium nitride based compound semiconductor laser as claimed in claim 43, characterized in that said first and second compound semiconductors are gallium nitride based semiconductors.

45. The gallium nitride based compound semiconductor laser as claimed in claim 44, characterized in that said first and second compound semiconductor are ones selected from the group consisting of GaN, AlGaN, InGaN and InAlGaN.

46. The gallium nitride based compound semiconductor laser as claimed in claim 43, characterized in that said first and second compound semiconductors are boron nitride based semiconductors.

47. The gallium nitride based compound semiconductor laser as claimed in claim 31, characterized in that laminations of a plurality of said additional compound semiconductor layers of the same conductivity type as said compound semiconductor base layer extend on both side walls and a top surface of said current block layer and also extending over said compound semiconductor base layer under said stripe-shaped opening under said stripe-shaped opening of said dielectric stripe masks.

48. The gallium nitride based compound semiconductor laser as claimed in claim 31, characterized in that side walls of said current block layers are vertical side walls.

49. The gallium nitride based compound semiconductor laser as claimed in claim 31, characterized in that side walls of said current block layers are sloped side walls.

50. The gallium nitride based compound semiconductor laser as claimed in claim 31, characterized in that said current block layer is selectively grown by a metal organic chemical vapor deposition method.

51. A gallium nitride based compound semiconductor laser having a current block layer structure which comprises current block layers of a first compound semiconductor having a hexagonal crystal structure, said current block layers being selectively grown on both a flat base portion and side walls of a ridged portion of a compound semiconductor re-

5 gion of a second compound semiconductor having said hexagonal crystal structure by use of dielectric stripe masks defining at least a stripe-shaped opening and being provided on a top portion of said ridged portion.

52. The gallium nitride based compound semiconductor laser as claimed in claim 51, characterized in that said hexagonal crystal structure has a face tilted from a (0001)-face by an angle in the range of 0 degree to 10 degrees, and characterized in that said stripe-shaped opening of said dielectric stripe masks has a longitudinal direction having an included angle to a [11-20] direction in the range of -5 degrees to ± 5 degrees.

53. The gallium nitride based compound semiconductor laser as claimed in claim 52, characterized in that said face of said hexagonal crystal structure is said (0001)-face.

54. The gallium nitride based compound semiconductor laser as claimed in claim 52, characterized in that said longitudinal direction of said stripe-shaped opening of said dielectric stripe masks is parallel to said [11-20] direction.

55. The gallium nitride based compound semiconductor laser as claimed in claim 51, characterized in that said hexagonal crystal structure has a face tilted from a (0001)-face by an angle in the range of 0 degree to 10 degrees, and characterized in that said stripe-shaped opening of said dielectric stripe masks has a longitudinal direction having an included angle to a [1-100] direction in the range of -5 degrees to ± 5 degrees.

56. The gallium nitride based compound semiconductor laser as claimed in claim 55, characterized in that said face of said hexagonal crystal structure is said (0001)-face.

57. The gallium nitride based compound semiconductor laser as claimed in claim 55, characterized in that said longitudinal direction of said stripe-shaped opening of said dielectric stripe masks is parallel to said [1-100] direction.

58. The gallium nitride based compound semiconductor laser as claimed in claim 51, characterized in that said first compound semiconductor is of an opposite conductivity type to that of said second compound semiconductor.

59. The gallium nitride based compound semiconductor laser as claimed in claim 58, characterized in that said first and second compound semiconductors are gallium nitride based semiconductors.

60. The gallium nitride based compound semiconductor laser as claimed in claim 59, characterized in that said first and second compound semiconductors are ones selected from the group consisting of GaN, AlGaN, InGaN and InAlGaN.

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61. The gallium nitride based compound semiconductor laser as claimed in claim 58, characterized in that said first and second compound semiconductors are boron nitride based semiconductors.

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62. The gallium nitride based compound semiconductor laser as claimed in claim 61, characterized in that said first compound semiconductor has a highly resistive compound semiconductor.

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63. The gallium nitride based compound semiconductor laser as claimed in claim 62, characterized in that said highly resistive compound semiconductor is an undoped semiconductor.

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64. The gallium nitride based compound semiconductor laser as claimed in claim 63, characterized in that said first and second compound semiconductors are gallium nitride based semiconductors.

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65. The gallium nitride based compound semiconductor laser as claimed in claim 64, characterized in that said first and second compound semiconductors are ones selected from the group consisting of GaN, AlGaN, InGaN and InAlGaN.

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66. The gallium nitride based compound semiconductor laser as claimed in claim 63, characterized in that said first and second compound semiconductors are boron nitride based semiconductors.

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67. The gallium nitride based compound semiconductor laser as claimed in claim 51, characterized in that each of said current block layers comprises a single layer having a top surface which is substantially the same level as said top portion of said ridged portion.

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68. The gallium nitride based compound semiconductor laser as claimed in claim 51, characterized in that each of said current block layers comprises laminations of a plurality of different layers and said laminations have a top surface which is substantially the same level as said top portion of said ridged portion.

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69. The gallium nitride based compound semiconductor laser as claimed in claim 68, characterized in that said laminations comprise a first layer having an opposite conductivity type to said compound semiconductor region, a second layer being laminated on said first layer and having the same con-

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ductivity type as said compound semiconductor region, and a third layer being laminated on said second layer and having said opposite conductivity type to said compound semiconductor region.

70. The gallium nitride based compound semiconductor laser as claimed in claim 51, characterized in that said ridged portion includes laminations of a plurality of different compound semiconductor layers.

71. The gallium nitride based compound semiconductor laser as claimed in claim 51, characterized in that said ridged portion and said flat base portion comprises a single compound semiconductor layer having a ridged portion and etched portions.

72. The gallium nitride based compound semiconductor laser as claimed in claim 1, characterized in that said current block layer is selectively grown by a metal organic chemical vapor deposition method.

73. A gallium nitride based compound semiconductor laser comprising :

a substrate ;
 a first $\text{In}_x\text{Al}_y\text{Ga}_{1-x-y}\text{N}$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer of a first conductivity type formed over said substrate and said first $\text{In}_x\text{Al}_y\text{Ga}_{1-x-y}\text{N}$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer having a hexagonal crystal structure ;
 $\text{In}_x\text{Ga}_{1-x}\text{N}$ ($0 \leq x \leq 1$) current block layers having said hexagonal crystal structure being selectively grown on a flat surface of said first $\text{In}_x\text{Al}_y\text{Ga}_{1-x-y}\text{N}$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer by use of dielectric stripe masks defining a ridge-shaped opening and being provided on said flat surface of said first $\text{In}_x\text{Al}_y\text{Ga}_{1-x-y}\text{N}$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer ;
 a second $\text{In}_x\text{Al}_y\text{Ga}_{1-x-y}\text{N}$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer of said first conductivity type being formed which extends on both side walls and top surfaces of said current block layers and also extends over said first $\text{In}_x\text{Al}_y\text{Ga}_{1-x-y}\text{N}$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer ;
 an active region of an $\text{In}_x\text{Al}_y\text{Ga}_{1-x-y}\text{N}$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) compound semiconductor formed over said second $\text{In}_x\text{Al}_y\text{Ga}_{1-x-y}\text{N}$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer ; and
 a third $\text{In}_x\text{Al}_y\text{Ga}_{1-x-y}\text{N}$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer of a second conductivity type formed over said active region.

74. The gallium nitride based compound semiconductor laser as claimed in claim 73, characterized in that said hexagonal crystal structure has a face tilted from a (0001)-face by an angle in the range of 0 degree to 10 degrees, and characterized in that

said stripe-shaped opening of said dielectric stripe masks have a longitudinal direction having an included angle to a [11-20] direction in the range of -5 degrees to ± 5 degrees.

75. The gallium nitride based compound semiconductor laser as claimed in claim 73, characterized in that said hexagonal crystal structure has a face tilted from a (0001)-face by an angle in the range of 0 degree to 10 degrees, and characterized in that said stripe-shaped opening of said dielectric stripe masks have a longitudinal direction having an included angle to a [1-100] direction in the range of -5 degrees to ± 5 degrees.

76. The gallium nitride based compound semiconductor laser as claimed in claim 73, characterized in that said $In_xGa_{1-x}N$ ($0 \leq x \leq 1$) current block layers are doped with an impurity of a second conductivity type.

77. The gallium nitride based compound semiconductor laser as claimed in claim 73, characterized in that said $In_xGa_{1-x}N$ ($0 \leq x \leq 1$) current block layers are undoped to have a high resistivity.

78. The gallium nitride based compound semiconductor laser as claimed in claim 73, characterized in that side walls of said current block layers are sloped side walls.

79. The gallium nitride based compound semiconductor laser as claimed in claim 73, characterized in that said current block layer is selectively grown by a metal organic chemical vapor deposition method.

80. A gallium nitride based compound semiconductor laser comprising :

a substrate ;
 a first $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer of a first conductivity type formed over said substrate and said first $InAlGaN$ layer having a hexagonal crystal structure ;
 an active region of an $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) compound semiconductor having said hexagonal crystal structure and being formed over said first $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer ;
 a second $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer of a second conductivity type being formed on said active region and said second $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer having said hexagonal crystal structure ;
 dielectric stripe masks being provided on said

5 second $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer and said dielectric stripe masks defining a stripe-shaped opening ; and an $In_xGa_{1-x}N$ ($0 \leq x \leq 1$) layer of said second conductivity type having said hexagonal crystal structure being selectively grown by use of said dielectric stripe masks so that said $In_xGa_{1-x}N$ ($0 \leq x \leq 1$) layer extends over said stripe-shaped opening and also extends over parts of said dielectric stripe masks whereby said $In_xGa_{1-x}N$ ($0 \leq x \leq 1$) layer has a ridge-shape.

10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120 125 130 135 140 145 150 155 160 165 170 175 180 185 190 195 200 205 210 215 220 225 230 235 240 245 250 255 260 265 270 275 280 285 290 295 300 305 310 315 320 325 330 335 340 345 350 355 360 365 370 375 380 385 390 395 400 405 410 415 420 425 430 435 440 445 450 455 460 465 470 475 480 485 490 495 500 505 510 515 520 525 530 535 540 545 550 555 560 565 570 575 580 585 590 595 600 605 610 615 620 625 630 635 640 645 650 655 660 665 670 675 680 685 690 695 700 705 710 715 720 725 730 735 740 745 750 755 760 765 770 775 780 785 790 795 800 805 810 815 820 825 830 835 840 845 850 855 860 865 870 875 880 885 890 895 900 905 910 915 920 925 930 935 940 945 950 955 960 965 970 975 980 985 990 995 1000 1005 1010 1015 1020 1025 1030 1035 1040 1045 1050 1055 1060 1065 1070 1075 1080 1085 1090 1095 1100 1105 1110 1115 1120 1125 1130 1135 1140 1145 1150 1155 1160 1165 1170 1175 1180 1185 1190 1195 1200 1205 1210 1215 1220 1225 1230 1235 1240 1245 1250 1255 1260 1265 1270 1275 1280 1285 1290 1295 1300 1305 1310 1315 1320 1325 1330 1335 1340 1345 1350 1355 1360 1365 1370 1375 1380 1385 1390 1395 1400 1405 1410 1415 1420 1425 1430 1435 1440 1445 1450 1455 1460 1465 1470 1475 1480 1485 1490 1495 1500 1505 1510 1515 1520 1525 1530 1535 1540 1545 1550 1555 1560 1565 1570 1575 1580 1585 1590 1595 1600 1605 1610 1615 1620 1625 1630 1635 1640 1645 1650 1655 1660 1665 1670 1675 1680 1685 1690 1695 1700 1705 1710 1715 1720 1725 1730 1735 1740 1745 1750 1755 1760 1765 1770 1775 1780 1785 1790 1795 1800 1805 1810 1815 1820 1825 1830 1835 1840 1845 1850 1855 1860 1865 1870 1875 1880 1885 1890 1895 1900 1905 1910 1915 1920 1925 1930 1935 1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005 2010 2015 2020 2025 2030 2035 2040 2045 2050 2055 2060 2065 2070 2075 2080 2085 2090 2095 2100 2105 2110 2115 2120 2125 2130 2135 2140 2145 2150 2155 2160 2165 2170 2175 2180 2185 2190 2195 2200 2205 2210 2215 2220 2225 2230 2235 2240 2245 2250 2255 2260 2265 2270 2275 2280 2285 2290 2295 2300 2305 2310 2315 2320 2325 2330 2335 2340 2345 2350 2355 2360 2365 2370 2375 2380 2385 2390 2395 2400 2405 2410 2415 2420 2425 2430 2435 2440 2445 2450 2455 2460 2465 2470 2475 2480 2485 2490 2495 2500 2505 2510 2515 2520 2525 2530 2535 2540 2545 2550 2555 2560 2565 2570 2575 2580 2585 2590 2595 2600 2605 2610 2615 2620 2625 2630 2635 2640 2645 2650 2655 2660 2665 2670 2675 2680 2685 2690 2695 2700 2705 2710 2715 2720 2725 2730 2735 2740 2745 2750 2755 2760 2765 2770 2775 2780 2785 2790 2795 2800 2805 2810 2815 2820 2825 2830 2835 2840 2845 2850 2855 2860 2865 2870 2875 2880 2885 2890 2895 2900 2905 2910 2915 2920 2925 2930 2935 2940 2945 2950 2955 2960 2965 2970 2975 2980 2985 2990 2995 3000 3005 3010 3015 3020 3025 3030 3035 3040 3045 3050 3055 3060 3065 3070 3075 3080 3085 3090 3095 3100 3105 3110 3115 3120 3125 3130 3135 3140 3145 3150 3155 3160 3165 3170 3175 3180 3185 3190 3195 3200 3205 3210 3215 3220 3225 3230 3235 3240 3245 3250 3255 3260 3265 3270 3275 3280 3285 3290 3295 3300 3305 3310 3315 3320 3325 3330 3335 3340 3345 3350 3355 3360 3365 3370 3375 3380 3385 3390 3395 3400 3405 3410 3415 3420 3425 3430 3435 3440 3445 3450 3455 3460 3465 3470 3475 3480 3485 3490 3495 3500 3505 3510 3515 3520 3525 3530 3535 3540 3545 3550 3555 3560 3565 3570 3575 3580 3585 3590 3595 3600 3605 3610 3615 3620 3625 3630 3635 3640 3645 3650 3655 3660 3665 3670 3675 3680 3685 3690 3695 3700 3705 3710 3715 3720 3725 3730 3735 3740 3745 3750 3755 3760 3765 3770 3775 3780 3785 3790 3795 3800 3805 3810 3815 3820 3825 3830 3835 3840 3845 3850 3855 3860 3865 3870 3875 3880 3885 3890 3895 3900 3905 3910 3915 3920 3925 3930 3935 3940 3945 3950 3955 3960 3965 3970 3975 3980 3985 3990 3995 4000 4005 4010 4015 4020 4025 4030 4035 4040 4045 4050 4055 4060 4065 4070 4075 4080 4085 4090 4095 4100 4105 4110 4115 4120 4125 4130 4135 4140 4145 4150 4155 4160 4165 4170 4175 4180 4185 4190 4195 4200 4205 4210 4215 4220 4225 4230 4235 4240 4245 4250 4255 4260 4265 4270 4275 4280 4285 4290 4295 4300 4305 4310 4315 4320 4325 4330 4335 4340 4345 4350 4355 4360 4365 4370 4375 4380 4385 4390 4395 4400 4405 4410 4415 4420 4425 4430 4435 4440 4445 4450 4455 4460 4465 4470 4475 4480 4485 4490 4495 4500 4505 4510 4515 4520 4525 4530 4535 4540 4545 4550 4555 4560 4565 4570 4575 4580 4585 4590 4595 4600 4605 4610 4615 4620 4625 4630 4635 4640 4645 4650 4655 4660 4665 4670 4675 4680 4685 4690 4695 4700 4705 4710 4715 4720 4725 4730 4735 4740 4745 4750 4755 4760 4765 4770 4775 4780 4785 4790 4795 4800 4805 4810 4815 4820 4825 4830 4835 4840 4845 4850 4855 4860 4865 4870 4875 4880 4885 4890 4895 4900 4905 4910 4915 4920 4925 4930 4935 4940 4945 4950 4955 4960 4965 4970 4975 4980 4985 4990 4995 5000 5005 5010 5015 5020 5025 5030 5035 5040 5045 5050 5055 5060 5065 5070 5075 5080 5085 5090 5095 5100 5105 5110 5115 5120 5125 5130 5135 5140 5145 5150 5155 5160 5165 5170 5175 5180 5185 5190 5195 5200 5205 5210 5215 5220 5225 5230 5235 5240 5245 5250 5255 5260 5265 5270 5275 5280 5285 5290 5295 5300 5305 5310 5315 5320 5325 5330 5335 5340 5345 5350 5355 5360 5365 5370 5375 5380 5385 5390 5395 5400 5405 5410 5415 5420 5425 5430 5435 5440 5445 5450 5455 5460 5465 5470 5475 5480 5485 5490 5495 5500 5505 5510 5515 5520 5525 5530 5535 5540 5545 5550 5555 5560 5565 5570 5575 5580 5585 5590 5595 5600 5605 5610 5615 5620 5625 5630 5635 5640 5645 5650 5655 5660 5665 5670 5675 5680 5685 5690 5695 5700 5705 5710 5715 5720 5725 5730 5735 5740 5745 5750 5755 5760 5765 5770 5775 5780 5785 5790 5795 5800 5805 5810 5815 5820 5825 5830 5835 5840 5845 5850 5855 5860 5865 5870 5875 5880 5885 5890 5895 5900 5905 5910 5915 5920 5925 5930 5935 5940 5945 5950 5955 5960 5965 5970 5975 5980 5985 5990 5995 6000 6005 6010 6015 6020 6025 6030 6035 6040 6045 6050 6055 6060 6065 6070 6075 6080 6085 6090 6095 6100 6105 6110 6115 6120 6125 6130 6135 6140 6145 6150 6155 6160 6165 6170 6175 6180 6185 6190 6195 6200 6205 6210 6215 6220 6225 6230 6235 6240 6245 6250 6255 6260 6265 6270 6275 6280 6285 6290 6295 6300 6305 6310 6315 6320 6325 6330 6335 6340 6345 6350 6355 6360 6365 6370 6375 6380 6385 6390 6395 6400 6405 6410 6415 6420 6425 6430 6435 6440 6445 6450 6455 6460 6465 6470 6475 6480 6485 6490 6495 6500 6505 6510 6515 6520 6525 6530 6535 6540 6545 6550 6555 6560 6565 6570 6575 6580 6585 6590 6595 6600 6605 6610 6615 6620 6625 6630 6635 6640 6645 6650 6655 6660 6665 6670 6675 6680 6685 6690 6695 6700 6705 6710 6715 6720 6725 6730 6735 6740 6745 6750 6755 6760 6765 6770 6775 6780 6785 6790 6795 6800 6805 6810 6815 6820 6825 6830 6835 6840 6845 6850 6855 6860 6865 6870 6875 6880 6885 6890 6895 6900 6905 6910 6915 6920 6925 6930 6935 6940 6945 6950 6955 6960 6965 6970 6975 6980 6985 6990 6995 7000 7005 7010 7015 7020 7025 7030 7035 7040 7045 7050 7055 7060 7065 7070 7075 7080 7085 7090 7095 7100 7105 7110 7115 7120 7125 7130 7135 7140 7145 7150 7155 7160 7165 7170 7175 7180 7185 7190 7195 7200 7205 7210 7215 7220 7225 7230 7235 7240 7245 7250 7255 7260 7265 7270 7275 7280 7285 7290 7295 7300 7305 7310 7315 7320 7325 7330 7335 7340 7345 7350 7355 7360 7365 7370 7375 7380 7385 7390 7395 7400 7405 7410 7415 7420 7425 7430 7435 7440 7445 7450 7455 7460 7465 7470 7475 7480 7485 7490 7495 7500 7505 7510 7515 7520 7525 7530 7535 7540 7545 7550 7555 7560 7565 7570 7575 7580 7585 7590 7595 7600 7605 7610 7615 7620 7625 7630 7635 7640 7645 7650 7655 7660 7665 7670 7675 7680 7685 7690 7695 7700 7705 7710 7715 7720 7725 7730 7735 7740 7745 7750 7755 7760 7765 7770 7775 7780 7785 7790 7795 7800 7805 7810 7815 7820 7825 7830 7835 7840 7845 7850 7855 7860 7865 7870 7875 7880 7885 7890 7895 7900 7905 7910 7915 7920 7925 7930 7935 7940 7945 7950 7955 7960 7965 7970 7975 7980 7985 7990 7995 8000 8005 8010 8015 8020 8025 8030 8035 8040 8045 8050 8055 8060 8065 8070 8075 8080 8085 8090 8095 8100 8105 8110 8115 8120 8125 8130 8135 8140 8145 8150 8155 8160 8165 8170 8175 8180 8185 8190 8195 8200 8205 8210 8215 8220 8225 8230 8235 8240 8245 8250 8255 8260 8265 8270 8275 8280 8285 8290 8295 8300 8305 8310 8315 8320 8325 8330 8335 8340 8345 8350 8355 8360 8365 8370 8375 8380 8385 8390 8395 8400 8405 8410 8415 8420 8425 8430 8435 8440 8445 8450 8455 8460 8465 8470 8475 8480 8485 8490 8495 8500 8505 8510 8515 8520 8525 8530 8535 8540 8545 8550 8555 8560 8565 8570 8575 8580 8585 8590 8595 8600 8605 8610 8615 8620 8625 8630 8635 8640 8645 8650 8655 8660 8665 8670 8675 8680 8685 8690 8695 8700 8705 8710 8715 8720 8725 8730 8735 8740 8745 8750 8755 8760 8765 8770 8775 8780 8785 8790 8795 8800 8805 8810 8815 8820 8825 8830 8835 8840 8845 8850 8855 8860 8865 8870 8875 8880 8885 8890 8895 8900 8905 8910 8915 8920 8925 8930 8935 8940 8945 8950 8955 8960 8965 8970 8975 8980 8985 8990 8995 9000 9005 9010 9015 9020 9025 9030 9035 9040 9045 9050 9055 9060 9065 9070 9075 9080 9085 9090 9095 9100 9105 9110 9115 9120 9125 9130 9135 9140 9145 9150 9155 9160 9165 9170 9175 9180 9185 9190 9195 9200 9205 9210 9215 9220 9225 9230 9235 9240 9245 9250 9255 9260 9265 9270 9275 9280 9285 9290 9295 9300 9305 9310 9315 9320 9325 9330 9335 9340 9345 9350 9355 9360 9365 9370 9375 9380 9385 9390 9395 9400 9405 9410 9415 9420 9425 9430 9435 9440 9445 9450 9455 9460 9465 9470 9475 9480 9485 9490 9495 9500 9505 9510 9515 9520 9525 9530 9535 9540 9545 9550 9555 9560 9565 9570 9575 9580 9585 9590 9595 9600 9605 9610 9615 9620 9625 9630 9635 9640 9645 9650 9655 9660 9665 9670 9675 9680 9685 9690 9695 9700 9705 9710 9715 9720 9725 9730 9735 9740 9745 9750 9755 9760 9765 9770 9775 9780 9785 9790 9795 9800 9805 9810 9815 9820 9825 9830 9835 9840 9845 9850 9855 9860 9865 9870 9875 9880 9885 9890 9895 9900 9905 9910 9915 9920 9925 9930 9935 9940 9945 9950 9955 9960 9965 9970 9975 9980 9985 9990 9995 9999

$0 \leq x+y \leq 1$) layer of a second conductivity type being formed on said active region and said second $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer having said hexagonal crystal structure;

$In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) current block layers having said hexagonal crystal structure being selectively grown on a flat surface of said second $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer by use of dielectric stripe masks defining a ridge-shaped opening and being provided on said flat surface of said second $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer; and

an $In_xGa_{1-x}N$ ($0 \leq x \leq 1$) layer of said second conductivity type having said hexagonal crystal structure being formed which extends on both side walls and top surfaces of said $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) current block layers and also extends over said second $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer.

88. The gallium nitride based compound semiconductor laser as claimed in claim 87, characterized in that said hexagonal crystal structure has a face tilted from a (0001)-face by an angle in the range of 0 degree to 10 degrees, and characterized in that said stripe-shaped opening of said dielectric stripe masks have a longitudinal direction having an included angle to a [11-20] direction in the range of -5 degrees to +5 degrees.

89. The gallium nitride based compound semiconductor laser as claimed in claim 87, characterized in that said hexagonal crystal structure has a face tilted from a (0001)-face by an angle in the range of 0 degree to 10 degrees, and characterized in that said stripe-shaped opening of said dielectric stripe masks have a longitudinal direction having an included angle to a [1-100] direction in the range of -5 degrees to +5 degrees.

90. The gallium nitride based compound semiconductor laser as claimed in claim 87, characterized in that side walls of said $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) current block layers are sloped side walls.

91. The gallium nitride based compound semiconductor laser as claimed in claim 87, characterized in that said $In_xGa_{1-x}N$ ($0 \leq x \leq 1$) layer is selectively grown by a metal organic chemical vapor deposition method.

92. A gallium nitride based compound semiconductor laser comprising:

a substrate;

a first $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer of a first conductivity type being formed on a part of said substrate and said first $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer having a hexagonal crystal structure and said first $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer having a ridged portion;

an active region of an $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) compound semiconductor being formed on said ridged portion of said first $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer;

a second $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer of a second conductivity type being formed on said active region thereby to form a ridge-structure on said substrate, characterized in that said ridge-structure comprising laminations of said first $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer, said active region and said second $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer;

$In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) current block layers having said hexagonal crystal structure being selectively grown on side walls of said ridged-structure and over said first $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer by use of dielectric stripe mask provided on said ridge-structure; and

a third $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer of said second conductivity type being formed over said $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) current block layers and a top of said ridged-structure.

93. The gallium nitride based compound semiconductor laser as claimed in claim 92, characterized in that said hexagonal crystal structure has a face tilted from a (0001)-face by an angle in the range of 0 degree to 10 degrees, and characterized in that said stripe-shaped opening of said dielectric stripe masks have a longitudinal direction having an included angle to a [11-20] direction in the range of -5 degrees to +5 degrees.

94. The gallium nitride based compound semiconductor laser as claimed in claim 92, characterized in that said hexagonal crystal structure has a face tilted from a (0001)-face by an angle in the range of 0 degree to 10 degrees, and characterized in that said stripe-shaped opening of said dielectric stripe masks have a longitudinal direction having an included angle to a [1-100] direction in the range of -5 degrees to +5 degrees.

95. The gallium nitride based compound semiconductor laser as claimed in claim 92, characterized

in that said $In_xGa_{1-x}N$ ($0 \leq x \leq 1$) layer is selectively grown by a metal organic chemical vapor deposition method.

96. A gallium nitride based compound semiconductor laser comprising :

a substrate ;
 a first $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer of a first conductivity type being formed on said substrate and said first $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer having a hexagonal crystal structure and said first $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer having a ridged portion ;
 an active region of an $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) compound semiconductor being formed on said first $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer ;
 a second $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer of a second conductivity type being formed on said active region and said second $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer having a ridge portion and flat base portions ;
 $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) current block layers having said hexagonal crystal structure being selectively grown on side walls of said ridge portion and over said flat base portions by use of dielectric stripe mask provided on said ridge portion ; and
 a third $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) layer of said second conductivity type being formed over said $In_xAl_yGa_{1-x-y}N$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$, $0 \leq x+y \leq 1$) current block layers and a top of said ridge portion.

97. The gallium nitride based compound semiconductor laser as claimed in claim 96, characterized in that said hexagonal crystal structure has a face tilted from a (0001)-face by an angle in the range of 0 degree to 10 degrees, and characterized in that said stripe-shaped opening of said dielectric stripe masks have a longitudinal direction having an included angle to a [11-20] direction in the range of -5 degrees to +5 degrees.

98. The gallium nitride based compound semiconductor laser as claimed in claim 96, characterized in that said hexagonal crystal structure has a face tilted from a (0001)-face by an angle in the range of 0 degree to 10 degrees, and characterized in that said stripe-shaped opening of said dielectric stripe masks have a longitudinal direction having an included angle to a [1-100] direction in the range of -5 degrees to +5 degrees.

99. The gallium nitride based compound semicon-

ductor laser as claimed in claim 96, characterized in that said $In_xGa_{1-x}N$ ($0 \leq x \leq 1$) layer is selectively grown by a metal organic chemical vapor deposition method.

100. A current confinement structure in a semiconductor laser, comprising :

dielectric stripe masks defining a stripe-shaped opening and being provided on a flat surface of a compound semiconductor base layer having a hexagonal crystal structure ; and
 a compound semiconductor ridge-shaped layer of a hexagonal crystal structure being selectively grown in said stripe-shaped opening over said compound semiconductor base layer as well as over parts of said dielectric stripe masks..

101. The current confinement structure as claimed in claim 100, characterized in that said hexagonal crystal structure has a face tilted from a (0001)-face by an angle in the range of 0 degree to 10 degrees, and characterized in that said stripe-shaped opening of said dielectric stripe masks have a longitudinal direction having an included angle to a [11-20] direction in the range of -5 degrees to +5 degrees.

102. The current confinement structure as claimed in claim 100, characterized in that said hexagonal crystal structure has a face tilted from a (0001)-face by an angle in the range of 0 degree to 10 degrees, and characterized in that said stripe-shaped opening of said dielectric stripe masks have a longitudinal direction having an included angle to a [1-100] direction in the range of -5 degrees to +5 degrees.

103. The current confinement structure as claimed in claim 100, characterized in that said compound semiconductor base layer and said compound semiconductor ridge-shaped layer are made of one selected from the group consisting of gallium nitride based semiconductors and boron nitride based semiconductors.

104. The current confinement structure as claimed in claim 100, characterized in that said current block layer is selectively grown by a metal organic chemical vapor deposition method.

105. A method of forming a current block layer structure comprising the steps of:

providing dielectric stripe masks defining at least a stripe-shaped opening on a surface of a compound semiconductor region having a hexagonal crystal structure ; and
 selectively growing at least a current block lay-

er of a compound semiconductor having said hexagonal crystal structure on said surface of said compound semiconductor region by use of said dielectric stripe masks.

106. The method as claimed in claim 105, characterized in that said hexagonal crystal structure has a face tilted from a (0001)-face by an angle in the range of 0 degree to 10 degrees, and characterized in that said stripe-shaped opening of said dielectric stripe masks have a longitudinal direction having an included angle to a [11-20] direction in the range of -5 degrees to +5 degrees.

107. The method as claimed in claim 105, characterized in that said hexagonal crystal structure has a face tilted from a (0001)-face by an angle in the range of 0 degree to 10 degrees, and characterized in that said stripe-shaped opening of said dielectric stripe masks have a longitudinal direction having an included angle to a [1-100] direction in the range of -5 degrees to +5 degrees.

108. The method as claimed in claim 105, characterized in that said compound semiconductor of said current block layer is of an opposite conductivity type to that of said compound semiconductor region.

109. The method as claimed in claim 108, characterized in that said compound semiconductor of said current block layer and said compound semiconductor region are gallium nitride based semiconductors.

110. The method as claimed in claim 108, characterized in that said compound semiconductor of said current block layer and said compound semiconductor region are boron nitride based semiconductors.

111. The method as claimed in claim 105, characterized in that said compound semiconductor of said current block layer has a highly resistive compound semiconductor.

112. The method as claimed in claim 111, characterized in that said highly resistive compound semiconductor is an undoped semiconductor.

113. The method as claimed in claim 105, characterized in that said compound semiconductor region comprises a compound semiconductor base layer having a flat top surface, and characterized in that said current block layer is selectively grown on said flat top surface of said compound semiconductor base layer by use of said dielectric stripe masks provided on said flat top surface of said compound

semiconductor base layer.

114. The method as claimed in claim 105, further comprising the step of forming an additional compound semiconductor layer of the same conductivity type as said compound semiconductor base layer so that said additional compound semiconductor layer extends on both side walls and a top surface of said current block layer and also extends over said compound semiconductor base layer under said stripe-shaped opening under said stripe-shaped opening.

115. The method as claimed in claim 105, further comprising the step of forming laminations of a plurality of additional compound semiconductor layers of the same conductivity type as said compound semiconductor base layer so that said laminations of said plurality of additional compound semiconductor layers extend on both side walls and a top surface of said current block layer and also extend over said compound semiconductor base layer under said stripe-shaped opening.

116. The method as claimed in claim 105, characterized in that said compound semiconductor region includes at least a flat base portion and at least a ridged portion, and characterized in that said current block layer is selectively grown both on said flat base portion and on side walls of said ridged portion by use of said dielectric stripe masks provided on a top portion of said ridged portion.

117. The method as claimed in claim 116, characterized in that said current block layer comprises a single layer having a top surface which is substantially the same level as said top portion of said ridged portion.

118. The method as claimed in claim 116, characterized in that said current block layer comprises laminations of a plurality of different layers and said laminations have a top surface which is substantially the same level as said top portion of said ridged portion.

119. The method as claimed in claim 118, characterized in that said laminations are formed by depositing a first layer having an opposite conductivity type to said compound semiconductor region, depositing a second layer being laminated on said first layer and having the same conductivity type as said compound semiconductor region over said first layer, and a third layer being laminated on said second layer and having said opposite conductivity type to said compound semiconductor region over said second layer.

120. The method as claimed in claim 105, characterized in that said current block layer is selectively grown by a metal organic chemical vapor deposition method.

121. A method of forming a current block layer structure in a gallium nitride based compound semiconductor laser, comprising the steps of: providing dielectric stripe masks defining at least a stripe-shaped opening on a flat surface of a compound semiconductor region having a hexagonal crystal structure;

selectively growing at least a ridge-shaped current block layer of a compound semiconductor having said hexagonal crystal structure on said surface of said compound semiconductor region by use of said dielectric stripe masks; and forming at least an additional compound semiconductor layer of the same conductivity type as said compound semiconductor base layer so that said additional compound semiconductor layer extends on both side walls and a top surface of said current block layer and also extends over said compound semiconductor base layer under said stripe-shaped opening under said stripe-shaped opening.

122. The method as claimed in claim 121, characterized in that said hexagonal crystal structure has a face tilted from a (0001)-face by an angle in the range of 0 degree to 10 degrees, and characterized in that said stripe-shaped opening of said dielectric stripe masks have a longitudinal direction having an included angle to a [11-20] direction in the range of -5 degrees to +5 degrees.

123. The method as claimed in claim 121, characterized in that said hexagonal crystal structure has a face tilted from a (0001)-face by an angle in the range of 0 degree to 10 degrees, and characterized in that said stripe-shaped opening of said dielectric stripe masks have a longitudinal direction having an included angle to a [1-100] direction in the range of -5 degrees to +5 degrees.

124. The method as claimed in claim 121, characterized in that said compound semiconductor of said current block layer is of an opposite conductivity type to that of said compound semiconductor region.

125. The method as claimed in claim 121, characterized in that said compound semiconductor of said current block layer and said compound semiconductor region are gallium nitride based semiconductors.

5 126. The method as claimed in claim 121, characterized in that said compound semiconductor of said current block layer and said compound semiconductor region are boron nitride based semiconductors.

10 127. The method as claimed in claim 121, characterized in that said compound semiconductor of said current block layer has a highly resistive compound semiconductor.

15 128. The method as claimed in claim 127, characterized in that said highly resistive compound semiconductor is an undoped semiconductor.

20 129. The method as claimed in claim 121, characterized in that said current block layer is selectively grown by a metal organic chemical vapor deposition method.

25 130. A method of forming a current block layer structure in a gallium nitride based compound semiconductor laser, comprising the steps of:

forming flat base portions and ridged portions of a compound semiconductor region; providing dielectric stripe masks defining at least a stripe-shaped opening on said ridged portion of said compound semiconductor region having a hexagonal crystal structure; selectively growing at least a current block layer of a compound semiconductor having said hexagonal crystal structure both on said flat base portion and on side walls of said ridged portion by use of said dielectric stripe masks.

30 131. The method as claimed in claim 130, characterized in that said hexagonal crystal structure has a face tilted from a (0001)-face by an angle in the range of 0 degree to 10 degrees, and characterized in that said stripe-shaped opening of said dielectric stripe masks have a longitudinal direction having an included angle to a [11-20] direction in the range of -5 degrees to +5 degrees.

35 40 45 50 132. The method as claimed in claim 130, characterized in that said hexagonal crystal structure has a face tilted from a (0001)-face by an angle in the range of 0 degree to 10 degrees, and characterized in that said stripe-shaped opening of said dielectric stripe masks have a longitudinal direction having an included angle to a [1-100] direction in the range of -5 degrees to +5 degrees.

55 133. The method as claimed in claim 130, characterized in that said compound semiconductor of said current block layer is of an opposite conductivity type to that of said compound semiconductor re-

gion.

134. The method as claimed in claim 130, characterized in that said compound semiconductor of said current block layer and said compound semiconductor region are gallium nitride based semiconductors.

5

135. The method as claimed in claim 130, characterized in that said compound semiconductor of said current block layer and said compound semiconductor region are boron nitride based semiconductors.

10

136. The method as claimed in claim 130, characterized in that said compound semiconductor of said current block layer has a highly resistive compound semiconductor.

15

137. The method as claimed in claim 136, characterized in that said highly resistive compound semiconductor is an undoped semiconductor.

20

138. The method as claimed in claim 130, characterized in that said current block layer comprises a single layer having a top surface which is substantially the same level as said top portion of said ridged portion.

25

139. The method as claimed in claim 130, characterized in that said current block layer comprises laminations of a plurality of different layers and said laminations have a top surface which is substantially the same level as said top portion of said ridged portion.

30

140. The method as claimed in claim 139, characterized in that said laminations are formed by depositing a first layer having an opposite conductivity type to said compound semiconductor region, depositing a second layer being laminated on said first layer and having the same conductivity type as said compound semiconductor region over said first layer, and a third layer being laminated on said second layer and having said opposite conductivity type to said compound semiconductor region over said second layer.

35

141. The method as claimed in claim 130, characterized in that said current block layer is selectively grown by a metal organic chemical vapor deposition method.

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142. A method of forming a current confinement structure in a gallium nitride based compound semiconductor laser, comprising the steps of:

45

providing dielectric stripe masks defining at

least a stripe-shaped opening on a flat surface of a compound semiconductor region having a hexagonal crystal structure; and selectively growing a compound semiconductor ridge-shaped layer of a hexagonal crystal structure in said stripe-shaped opening over said compound semiconductor base layer as well as over parts of said dielectric stripe masks.

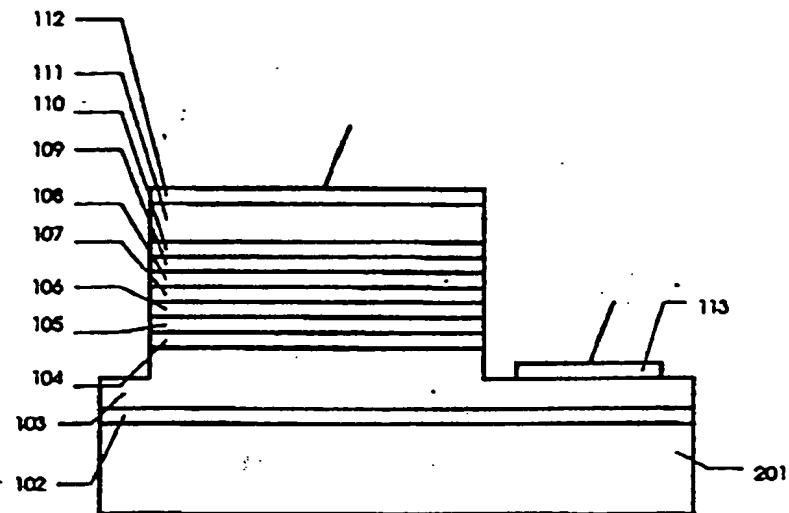
143. The method as claimed in claim 142, characterized in that said hexagonal crystal structure has a face tilted from a (0001)-face by an angle in the range of 0 degree to 10 degrees, and characterized in that said stripe-shaped opening of said dielectric stripe masks have a longitudinal direction having an included angle to a [11-20] direction in the range of -5 degrees to +5 degrees.

144. The method as claimed in claim 142, characterized in that said hexagonal crystal structure has a face tilted from a (0001)-face by an angle in the range of 0 degree to 10 degrees, and characterized in that said stripe-shaped opening of said dielectric stripe masks have a longitudinal direction having an included angle to a [1-100] direction in the range of -5 degrees to +5 degrees.

145. The method as claimed in claim 142, characterized in that said compound semiconductor region and said compound semiconductor ridge-shaped layer are made of one selected from the group consisting of gallium nitride based semiconductors and boron nitride based semiconductors.

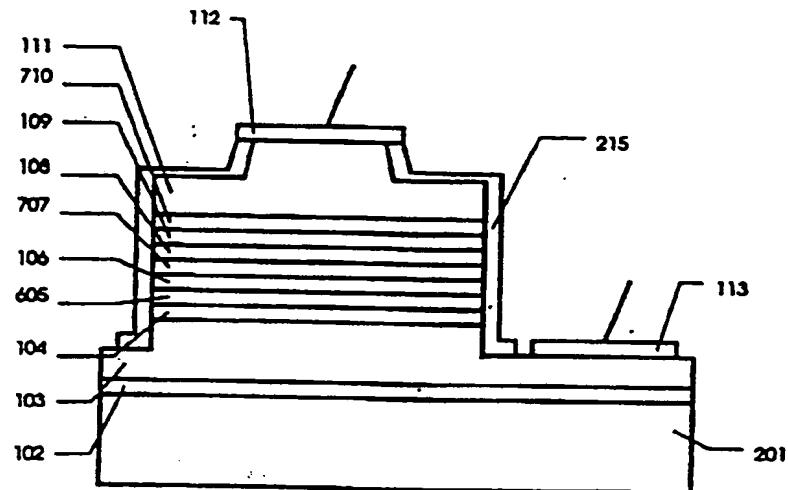
146. The method as claimed in claim 142, characterized in that said compound semiconductor ridge-shaped layer is selectively grown by a metal organic chemical vapor deposition method.

FIG. 1 prior art



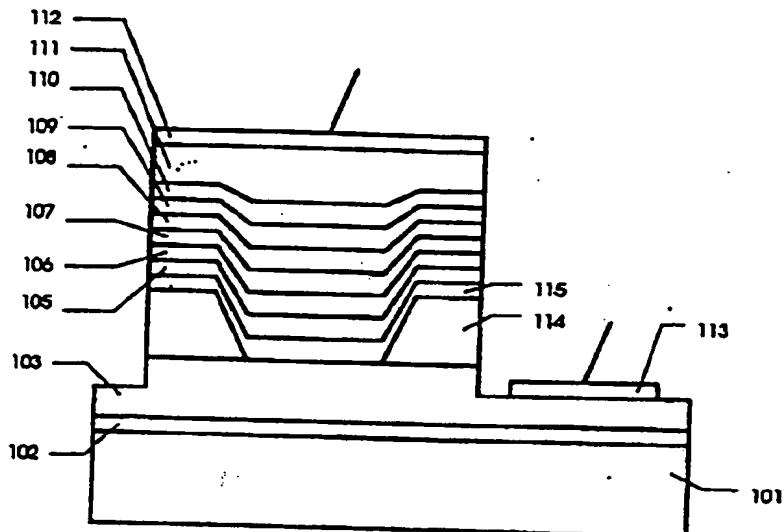
- 201 : (11-20)-face sapphire substrate
- 102 : 300 Å -thick undoped GaN buffer layer
- 103 : 3 μ m-thick n-type GaN contact layer doped with Si
- 104 : 0.1 μ m-thick n-type $\text{In}_{0.05}\text{Ga}_{0.95}\text{N}$ layer doped with Si
- 105 : 0.4 μ m-thick n-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer doped with Si
- 106 : 0.1 μ m-thick n-type GaN optical guide layer doped with Si
- 107 : multiple quantum well active layer of 7 periods of
25 Å -thick undoped $\text{In}_{0.2}\text{Ga}_{0.8}\text{N}$ quantum well layers and
50 Å -thick undoped $\text{In}_{0.05}\text{Ga}_{0.95}\text{N}$ barrier layers
- 108 : 200 Å -thick p-type $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$ layer doped with Mg
- 109 : 0.1 μ m-thick p-type GaN optical guide layer doped with Mg
- 110 : 0.4 μ m-thick p-type $\text{Al}_{0.7}\text{Ga}_{0.93}\text{N}$ cladding layer doped with Mg
- 111 : 0.2 μ m-thick p-type GaN contact layer doped with Mg
- 112 : p-electrode
- 113 : n-electrode

FIG. 2 prior art



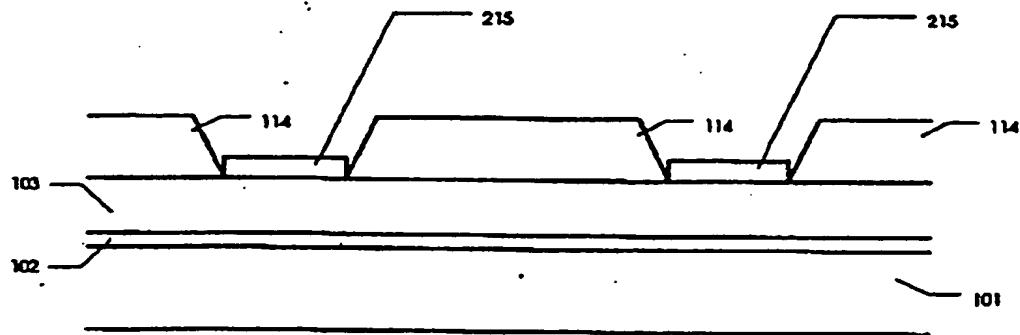
- 201 : (11-20)-face sapphire substrate
- 102 : 300 Å -thick undoped GaN buffer layer
- 103 : 3 μ m-thick n-type GaN contact layer doped with Si
- 104 : 0.1 μ m-thick n-type $In_{0.05}Ga_{0.95}N$ layer doped with Si
- 605 : 0.5 μ m-thick n-type $Al_{0.05}Ga_{0.95}N$ cladding layer doped with Si
- 106 : 0.1 μ m-thick n-type GaN optical guide layer doped with Si
- 707 : multiple quantum well active layer of 7 periods of
30 Å -thick undoped $In_{0.2}Ga_{0.8}N$ quantum well layers and
60 Å -thick undoped $In_{0.05}Ga_{0.95}N$ barrier layers
- 108 : 200 Å -thick p-type $Al_{0.2}Ga_{0.8}N$ layer doped with Mg
- 109 : 0.1 μ m-thick p-type GaN optical guide layer doped with Mg
- 710 : 0.5 μ m-thick p-type $Al_{0.05}Ga_{0.95}N$ cladding layer doped with Mg
- 111 : 0.2 μ m-thick p-type GaN contact layer doped with Mg
- 112 : p-electrode
- 113 : n-electrode
- 215 : silicon oxide film

FIG. 3



- 101 : (0001)-face sapphire substrate
- 102 : 300 Å-thick undoped GaN buffer layer
- 103 : 3 μ m-thick n-type GaN contact layer doped with Si
- 104 : 0.5 μ m-thick p-type GaN current block layer doped with Mg
- 105 : 0.1 μ m-thick n-type Al_{0.07}Ga_{0.93}N cladding layer doped with Si
- 106 : 0.4 μ m-thick n-type Al_{0.07}Ga_{0.93}N cladding layer doped with Si
- 107 : 0.1 μ m-thick n-type GaN optical guide layer doped with Si
- 108 : multiple quantum well active layer of 7 periods of
25 Å-thick undoped In_{0.2}Ga_{0.8}N quantum well layers and
50 Å-thick undoped In_{0.05}Ga_{0.95}N barrier layers
- 109 : 0.2 μ m-thick p-type GaN optical guide layer doped with Mg
- 110 : 0.4 μ m-thick p-type Al_{0.07}Ga_{0.93}N cladding layer doped with Mg
- 111 : 0.2 μ m-thick p-type GaN contact layer doped with Mg
- 112 : p-electrode
- 113 : n-electrode

FIG. 4



101 : (0001)-face sapphire substrate

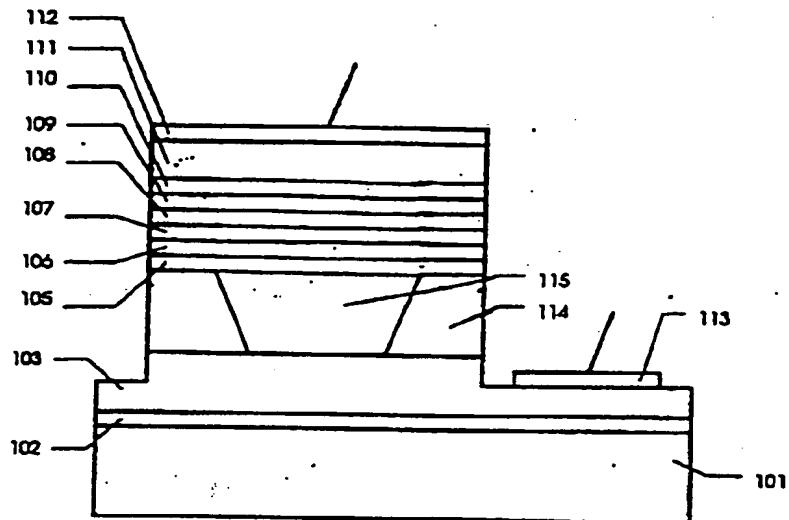
102 : 300 Å-thick undoped GaN buffer layer

103 : 3 μ m-thick n-type GaN contact layer doped with Si

114 : 0.5 μ m-thick p-type GaN current block layer doped with Mg

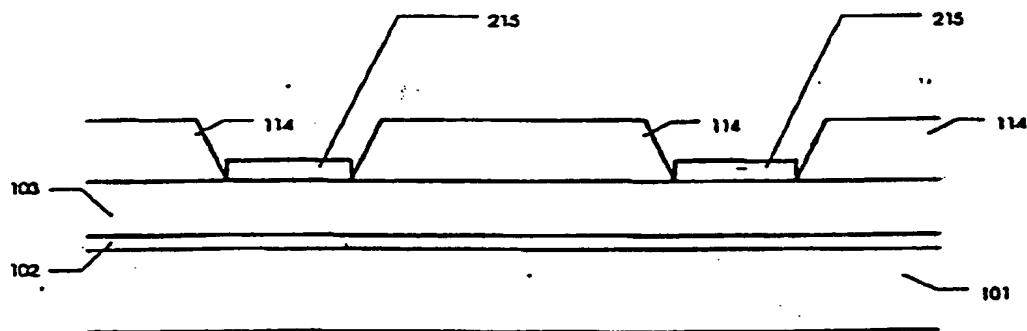
215 : silicon oxide stripe masks

FIG. 5



- 101 : (0001)-face sapphire substrate
- 102 : 300 Å-thick undoped GaN buffer layer
- 103 : 3 μ m-thick n-type GaN contact layer doped with Si
- 104 : 0.5 μ m-thick p-type GaN current block layer doped with Mg
- 105 : 0.4 μ m-thick n-type Al_{0.07}Ga_{0.93}N cladding layer doped with Si
- 106 : 0.1 μ m-thick n-type GaN optical guide layer doped with Si
- 107 : multiple quantum well active layer of 7 periods of
25 Å-thick undoped In_{0.2}Ga_{0.8}N quantum well layers and
50 Å-thick undoped In_{0.05}Ga_{0.95}N barrier layers
- 108 : 200 Å-thick p-type Al_{0.2}Ga_{0.8}N layer doped with Mg
- 109 : 0.1 μ m-thick p-type GaN optical guide layer doped with Mg
- 110 : 0.4 μ m-thick p-type Al_{0.07}Ga_{0.93}N cladding layer doped with Mg
- 111 : 0.2 μ m-thick p-type GaN contact layer doped with Mg
- 112 : p-electrode
- 113 : n-electrode

FIG. 6



101 : (0001)-face sapphire substrate

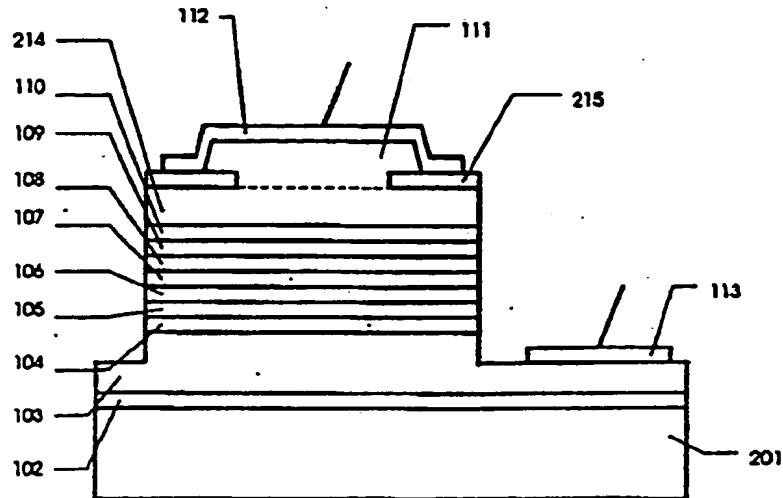
102 : 300 Å-thick undoped GaN buffer layer

103 : 3 μ m-thick n-type GaN contact layer doped with Si

114 : 0.5 μ m-thick p-type GaN current block layer doped with Mg

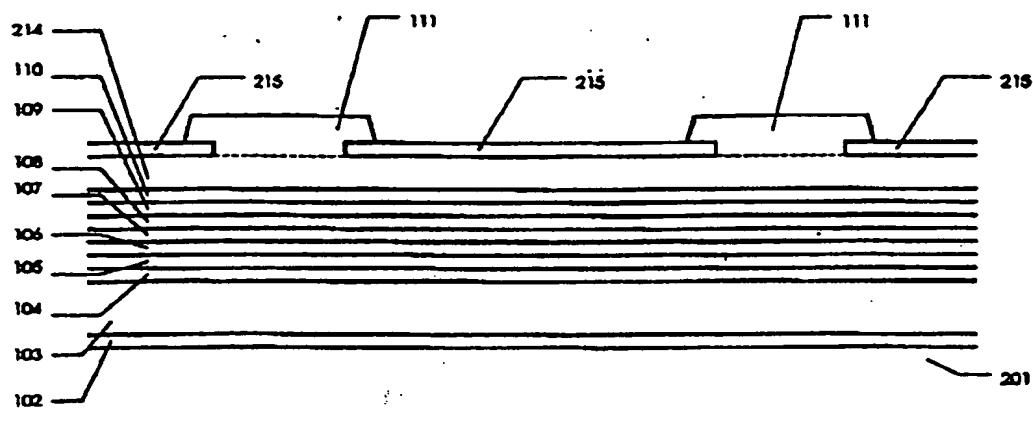
215 : silicon oxide stripe masks

FIG. 7



- 201 : (11-20)-face sapphire substrate
- 102 : 300 Å-thick undoped GaN buffer layer
- 103 : 3 μ m-thick n-type GaN contact layer doped with Si
- 104 : 0.1 μ m-thick n-type $\text{In}_{0.05}\text{Ga}_{0.95}\text{N}$ layer doped with Si
- 105 : 0.4 μ m-thick n-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer doped with Si
- 106 : 0.1 μ m-thick n-type GaN optical guide layer doped with Si
- 107 : multiple quantum well active layer of 7 periods of
25 Å-thick undoped $\text{In}_{0.2}\text{Ga}_{0.8}\text{N}$ quantum well layers and
50 Å-thick undoped $\text{In}_{0.05}\text{Ga}_{0.95}\text{N}$ barrier layers
- 108 : 200 Å-thick p-type $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$ layer doped with Mg
- 109 : 0.1 μ m-thick p-type GaN optical guide layer doped with Mg
- 110 : 0.4 μ m-thick p-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer doped with Mg
- 214 : 0.2 μ m-thick p-type GaN layer doped with Mg
- 215 : 2000 Å-thick silicon oxide stripe masks
- 111 : 0.3 μ m-thick p-type GaN contact layer doped with Mg
- 112 : p-electrode
- 113 : n-electrode

FIG. 8



201 : (11-20)-face sapphire substrate

102 : 300 Å-thick undoped GaN buffer layer

103 : 3 μ m-thick n-type GaN contact layer doped with Si

104 : 0.1 μ m-thick n-type In_{0.05}Ga_{0.95}N layer doped with Si

105 : 0.4 μ m-thick n-type Al_{0.07}Ga_{0.93}N cladding layer doped with Si

106 : 0.1 μ m-thick n-type GaN optical guide layer doped with Si

107 : multiple quantum well active layer of 7 periods of

25 Å-thick undoped In_{0.2}Ga_{0.8}N quantum well layers and
50 Å-thick undoped In_{0.05}Ga_{0.95}N barrier layers

108 : 200 Å-thick p-type Al_{0.2}Ga_{0.8}N layer doped with Mg

109 : 0.1 μ m-thick p-type GaN optical guide layer doped with Mg

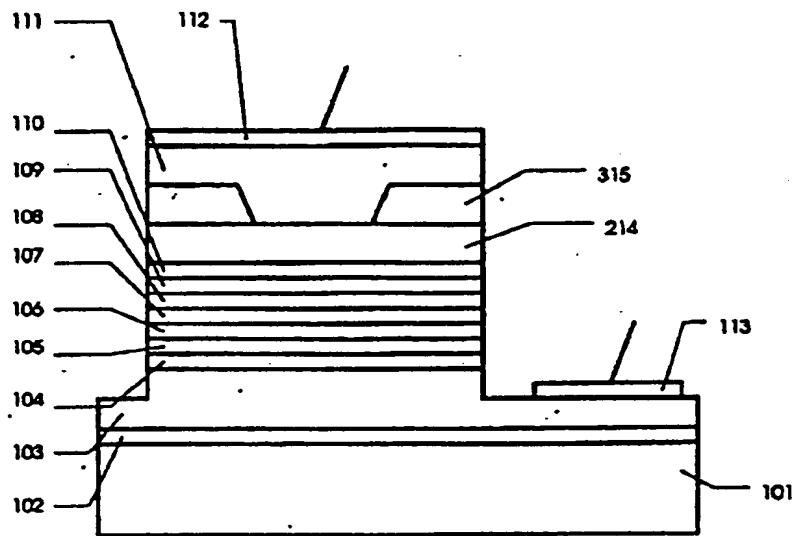
110 : 0.4 μ m-thick p-type Al_{0.07}Ga_{0.93}N cladding layer doped with Mg

214 : 0.2 μ m-thick p-type GaN layer doped with Mg

215 : 2000 Å-thick silicon oxide stripe masks

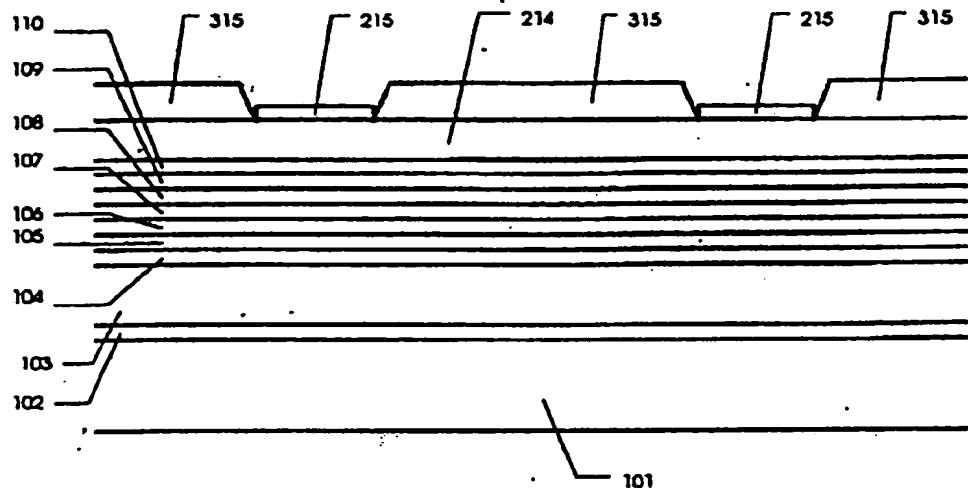
111 : 0.3 μ m-thick p-type GaN contact layer doped with Mg

FIG. 9



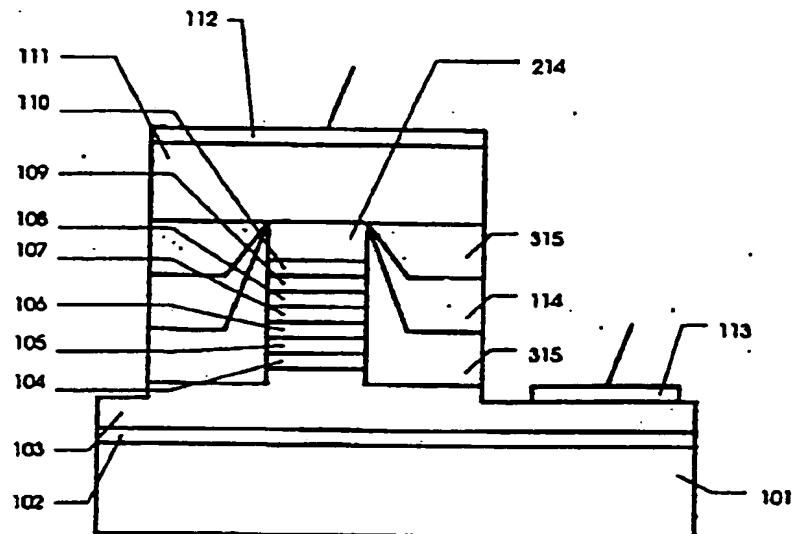
- 101 : (0001)-face sapphire substrate
- 102 : 300 Å-thick undoped GaN buffer layer
- 103 : 3 μ m-thick n-type GaN contact layer doped with Si
- 104 : 0.1 μ m-thick n-type $\text{In}_{0.05}\text{Ga}_{0.95}\text{N}$ layer doped with Si
- 105 : 0.4 μ m-thick n-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer doped with Si
- 106 : 0.1 μ m-thick n-type GaN optical guide layer doped with Si
- 107 : multiple quantum well active layer of 7 periods of
25 Å-thick undoped $\text{In}_{0.2}\text{Ga}_{0.8}\text{N}$ quantum well layers and
50 Å-thick undoped $\text{In}_{0.05}\text{Ga}_{0.95}\text{N}$ barrier layers
- 108 : 200 Å-thick p-type $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$ layer doped with Mg
- 109 : 0.1 μ m-thick p-type GaN optical guide layer doped with Mg
- 110 : 0.4 μ m-thick p-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer doped with Mg
- 214 : 0.2 μ m-thick p-type GaN layer doped with Mg
- 315 : 0.5 μ m-thick n-type GaN current block layer doped with Si
- 111 : 0.3 μ m-thick p-type GaN contact layer doped with Mg
- 112 : p-electrode
- 113 : n-electrode

FIG. 10



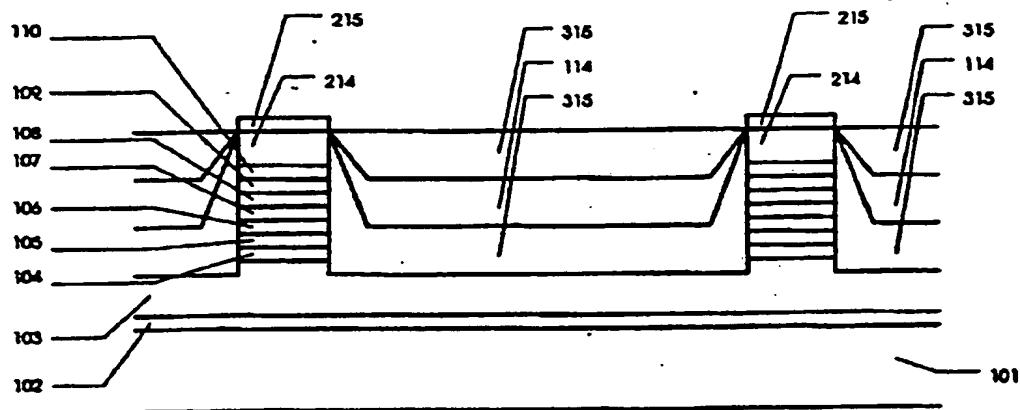
- 101 : (0001)-face sapphire substrate
- 102 : 300 Å-thick undoped GaN buffer layer
- 103 : 3 μ m-thick n-type GaN contact layer doped with Si
- 104 : 0.1 μ m-thick n-type $\text{In}_{0.05}\text{Ga}_{0.95}\text{N}$ layer doped with Si
- 105 : 0.4 μ m-thick n-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer doped with Si
- 106 : 0.1 μ m-thick n-type GaN optical guide layer doped with Si
- 107 : multiple quantum well active layer of 7 periods of
25 Å-thick undoped $\text{In}_{0.2}\text{Ga}_{0.8}\text{N}$ quantum well layers and
50 Å-thick undoped $\text{In}_{0.05}\text{Ga}_{0.95}\text{N}$ barrier layers
- 108 : 200 Å-thick p-type $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$ layer doped with Mg
- 109 : 0.1 μ m-thick p-type GaN optical guide layer doped with Mg
- 110 : 0.4 μ m-thick p-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer doped with Mg
- 214 : 0.2 μ m-thick p-type GaN layer doped with Mg
- 315 : 0.5 μ m-thick n-type GaN current block layer doped with Si
- 215 : silicon oxide stripe masks

FIG. 11



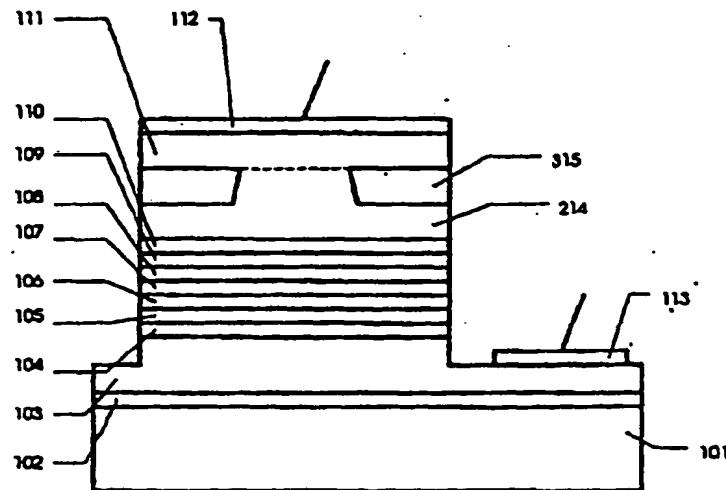
- 101 : (0001)-face sapphire substrate
- 102 : 300 Å-thick undoped GaN buffer layer
- 103 : 3 μ m-thick n-type GaN contact layer doped with Si
- 104 : 0.1 μ m-thick n-type $In_{0.05}Ga_{0.95}N$ layer doped with Si
- 105 : 0.4 μ m-thick n-type $Al_{0.07}Ga_{0.93}N$ cladding layer doped with Si
- 106 : 0.1 μ m-thick n-type GaN optical guide layer doped with Si
- 107 : multiple quantum well active layer of 7 periods of
25 Å-thick undoped $In_{0.2}Ga_{0.8}N$ quantum well layers and
50 Å-thick undoped $In_{0.05}Ga_{0.95}N$ barrier layers
- 108 : 200 Å-thick p-type $Al_{0.2}Ga_{0.8}N$ layer doped with Mg
- 109 : 0.1 μ m-thick p-type GaN optical guide layer doped with Mg
- 110 : 0.4 μ m-thick p-type $Al_{0.07}Ga_{0.93}N$ cladding layer doped with Mg
- 214 : 0.2 μ m-thick p-type GaN layer doped with Mg
- 315 : 0.5 μ m-thick n-type GaN current block layer doped with Si
- 114 : 0.5 μ m-thick p-type GaN current block layer doped with Mg
- 315 : 0.5 μ m-thick n-type GaN current block layer doped with Si
- 111 : 0.2 μ m-thick p-type GaN contact layer doped with Mg
- 112 : p-electrode
- 113 : n-electrode

FIG. 12



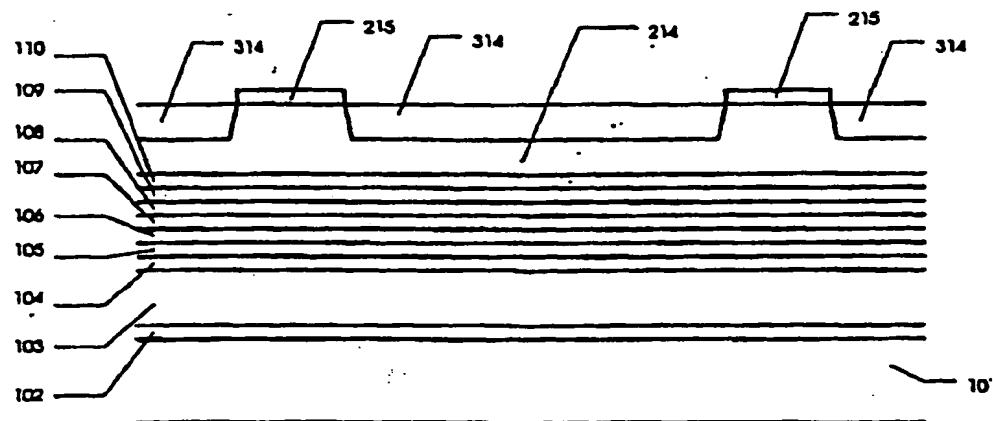
- 101 : (0001)-face sapphire substrate
- 102 : 300 Å-thick undoped GaN buffer layer
- 103 : 3 μ m-thick n-type GaN contact layer doped with Si
- 104 : 0.1 μ m-thick n-type $In_{0.05}Ga_{0.95}N$ layer doped with Si
- 105 : 0.4 μ m-thick n-type $Al_{0.07}Ga_{0.93}N$ cladding layer doped with Si
- 106 : 0.1 μ m-thick n-type GaN optical guide layer doped with Si
- 107 : multiple quantum well active layer of 7 periods of
25 Å-thick undoped $In_{0.2}Ga_{0.8}N$ quantum well layers and
50 Å-thick undoped $In_{0.05}Ga_{0.95}N$ barrier layers
- 108 : 200 Å-thick p-type $Al_{0.2}Ga_{0.8}N$ layer doped with Mg
- 109 : 0.1 μ m-thick p-type GaN optical guide layer doped with Mg
- 110 : 0.4 μ m-thick p-type $Al_{0.07}Ga_{0.93}N$ cladding layer doped with Mg
- 214 : 0.2 μ m-thick p-type GaN layer doped with Mg
- 315 : 0.5 μ m-thick n-type GaN current block layer doped with Si
- 114 : 0.5 μ m-thick p-type GaN current block layer doped with Mg
- 315 : 0.5 μ m-thick n-type GaN current block layer doped with Si
- 215 : silicon oxide stripe masks

FIG. 13



- 101 : (0001)-face sapphire substrate
- 102 : 300 Å-thick undoped GaN buffer layer
- 103 : 3 μ m-thick n-type GaN contact layer doped with Si
- 104 : 0.1 μ m-thick n-type $\text{In}_{0.05}\text{Ga}_{0.95}\text{N}$ layer doped with Si
- 105 : 0.4 μ m-thick n-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer doped with Si
- 106 : 0.1 μ m-thick n-type GaN optical guide layer doped with Si
- 107 : multiple quantum well active layer of 7 periods of
25 Å-thick undoped $\text{In}_{0.2}\text{Ga}_{0.8}\text{N}$ quantum well layers and
50 Å-thick undoped $\text{In}_{0.05}\text{Ga}_{0.95}\text{N}$ barrier layers
- 108 : 200 Å-thick p-type $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$ layer doped with Mg
- 109 : 0.1 μ m-thick p-type GaN optical guide layer doped with Mg
- 110 : 0.4 μ m-thick p-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer doped with Mg
- 214 : 0.2 μ m-thick p-type GaN layer doped with Mg
- 315 : 0.5 μ m-thick n-type GaN current block layer doped with Si
- 111 : 0.3 μ m-thick p-type GaN contact layer doped with Mg
- 112 : p-electrode
- 113 : n-electrode

FIG. 14



101 : (0001)-face sapphire substrate

102 : 300 Å-thick undoped GaN buffer layer

103 : 3 μ m-thick n-type GaN contact layer doped with Si

104 : 0.1 μ m-thick n-type $\text{In}_{0.05}\text{Ga}_{0.95}\text{N}$ layer doped with Si

105 : 0.4 μ m-thick n-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer doped with Si

106 : 0.1 μ m-thick n-type GaN optical guide layer doped with Si

107 : multiple quantum well active layer of 7 periods of

25 Å-thick undoped $\text{In}_{0.2}\text{Ga}_{0.8}\text{N}$ quantum well layers and

50 Å-thick undoped $\text{In}_{0.05}\text{Ga}_{0.95}\text{N}$ barrier layers

108 : 200 Å-thick p-type $\text{Al}_{0.2}\text{Ga}_{0.8}\text{N}$ layer doped with Mg

109 : 0.1 μ m-thick p-type GaN optical guide layer doped with Mg

110 : 0.4 μ m-thick p-type $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ cladding layer doped with Mg

214 : 0.2 μ m-thick p-type GaN layer doped with Mg

315 : 0.5 μ m-thick n-type GaN current block layer doped with Si

111 : 0.3 μ m-thick p-type GaN contact layer doped with Mg